

THE EFFECT OF PLYOMETRIC TRAINING ON THE PERFORMANCE OF CYCLISTS

BY

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DECLARATION

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

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SUMMARY

The purpose of this study was to determine the effect of plyometric exercise training on the aerobic and anaerobic capacities of well-trained cyclists.

Twenty male competitive cyclists (age: $24 \pm \text{SD } 5$ years, height: $180 \pm \text{SD } 6$ cm and body mass: $77 \pm \text{SD } 6$ kg), including 12 mountain bikers and eight road cyclists were randomly divided into an experimental ($n = 13$) and a control group ($n = 7$). Testing included kinanthropometric measurements, vertical jump test, bench pull test, maximal aerobic capacity test, indoor 5-kilometer time trial (TT), anaerobic capacity test (30-second Wingate test) and an outdoor 4.4-kilometer time trial (field test).

The plyometric training program had no statistically significant effect on the maximal aerobic capacity, anaerobic capacity, time trial performance (laboratory and field) and vertical jump performance of the experimental group. Selected outcome variables, i.e. $\text{VO}_{2\text{max}}$, PPO and MP during the Wingate test and time to complete the laboratory TT, bordered on statistical significance. The experimental group significantly improved their upper body strength. There was also a strong correlation between the outdoor TT and upper body strength ($r = 0.72$).

Although the plyometric training program did not significantly improve the performance of the cyclists, indications were that the experimental group improved their anaerobic power and upper body strength. One previous study in the literature suggested that the effects of a plyometric training program may only become evident a few weeks after completion of the program. It is therefore possible that the cyclists in this study would have experienced the benefits of plyometric training only later, i.e. closer to the competition season when the aim of their training program is to improve power and speed.

OPSOMMING

Die doel van die studie was om te bepaal wat die effek van pliometriese oefeninge is op die aërobie en anaërobie vermoëns van goed ingeefende fietsryers.

Twintig kompeterende mans fietsryers, (ouderdom: $24 \pm \text{SD } 5$ jaar, lengte: $180 \pm \text{SD } 6$ cm en gewig: $77 \pm \text{SD } 6$ kg), was ewekansig ingedeel in of 'n eksperimentele ($n = 13$) of 'n kontrole groep ($n = 7$). Die groep sluit twaalf bergfietsryers en agt padfietsryers in. Kinantropometriese metings, vertikale spronghoogte, 'n bolyf kragtoets ("bench pull test"), 'n maksimale aërobie uithouvermoë toets, 'n binneshuise 5-kilometer tydtoets (TT), 'n anaërobie kapasiteit toets (30-sekonde Wingate toets) en 'n buitemuurse 4.4-kilometer tydtoets (veldtoets) was voltooi gedurende die toetsperiode.

Die pliometriese oefenprogram het geen statisties betekenisvolle effek op maksimale aërobie kapasiteit, anaërobie kapasiteit, tydtoets prestasie (laboratorium en veld) of op vertikale spronghoogte van die eksperimentele groep gehad nie. Spesifieke uitkomsveranderlikes, soos $\text{VO}_{2\text{maks}}$, piek en gemiddelde kraguitset gedurende die Wingate toets, en die tyd wat dit geneem het om die laboratorium tydtoets te voltooi, het gegrens aan 'n statistiese betekenisvolle verbetering in die eksperimentele groep. Die eksperimentele groep het 'n betekenisvolle verbetering getoon in hul bolyfkrag na die intervensie. Daar was ook 'n sterk verband tussen die veld tydtoets en die bolyfkrag in die eksperimentele groep ($r = 0.72$).

Hoewel die pliometriese oefenprogram nie die prestasie van die fietsryers betekenisvol verbeter het nie, het dit tekens van verbetering in die eksperimentele groep se anaërobie en bolyfkrag getoon. 'n Vorige studie het voorgestel dat 'n pliometriese inoefeningsprogram slegs na 'n paar weke na die intervensie 'n effek sal toon in prestasie. Daarom is dit moontlik dat die fietsryers in die studie die voordele van pliometriese oefeninge eers later ervaar het, nader aan die kompetisiefase wanneer die doel van die oefenprogram is om spoed en krag te verbeter.

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LIST OF ABBREVIATIONS

| | | |
|--------------------|---|---|
| APT | : | aquatic plyometric training |
| ADP | : | adenosine diphosphate |
| ATP | : | adenosine triphosphate |
| bpm | : | beats per minute |
| BMC | : | bone mineral content |
| rpm | : | cadence (repetitions per minute) |
| Ca ²⁺ | : | calcium |
| CO ₂ | : | carbon dioxide |
| cm | : | centimeter(s) |
| CP | : | creatine phosphate |
| GET | : | gas-exchange threshold |
| HR | : | heart rate (beats per minute) |
| HR _{max} | : | maximum heart rate (beats per minute) |
| km | : | kilometer(s) |
| km.h ⁻¹ | : | kilometers per hour |
| LT | : | lactate (mL.kg ⁻¹ .min ⁻¹) |
| LT _{max} | : | maximum blood lactate concentration (mL.kg ⁻¹ .min ⁻¹) |
| VE | : | minute ventilation (L.min ⁻¹) |
| VE _{max} | : | maximum minute ventilation (L.min ⁻¹) |
| MHC | : | myosin heavy chain |
| N | : | nitrogen |
| 1RM | : | one-repetition maximal |
| OBLA | : | onset of blood lactate accumulation |
| O ₂ | : | oxygen |
| PRFD | : | peak-rate-of-force developments |
| PO | : | power output (W) |
| PO _{LT} | : | power output at lactate threshold (W) |
| PPO | : | peak power output (W) |
| RER | : | rate-exchange-ratio |

| | | |
|--------------------|---|--|
| s | : | second(s) |
| SEC | : | series elastic component |
| SD | : | standard deviation |
| SSC | : | stretch-shortening cycle |
| t | : | time |
| VO ₂ | : | volume of oxygen consumption |
| VO _{2max} | : | maximum oxygen consumption (L.min ⁻¹ , ml.kg ⁻¹ .min ⁻¹) |
| W | : | watts |
| W.sec | : | watts per second |
| W _{train} | : | total amount of work completed (watts) |

TABLE OF CONTENTS

| | <u>P.</u> |
|---|-----------|
| CHAPTER ONE: INTRODUCTION..... | 1 |
| CHAPTER TWO: PLYOMETRIC TRAINING..... | 3 |
| A. What is plyometrics?..... | 3 |
| B. The physiology of plyometric training..... | 4 |
| 1. The mechanical model..... | 4 |
| 2. The neurophysiological model..... | 5 |
| 3. The stretch shortening cycle model..... | 5 |
| C. Muscle physiology during exercise..... | 6 |
| D. Designing a plyometric training program..... | 13 |
| 1. Mode..... | 13 |
| 2. Intensity, frequency and duration..... | 15 |
| E. The effect of plyometric training on performance in various sports..... | 17 |
| F. The effect of plyometric training on cycling performance..... | 23 |
| G. Conclusion..... | 24 |

| | |
|---|----|
| CHAPTER THREE: PHYSIOLOGY OF CYCLING | 25 |
| A. Introduction | 25 |
| B. Predictors of cycling performance | 26 |
| 1. Maximal oxygen uptake (VO_{2max})..... | 27 |
| 2. Cycling economy and efficiency..... | 28 |
| 3. Mean and peak power output..... | 28 |
| 4. Lactate threshold..... | 29 |
| 5. Percentage type I muscle fibers in the <i>Vastus Lateralis</i> | 30 |
| 6. Body composition..... | 31 |
| C. Mountain biking | 32 |
| 1. Characteristics of mountain biking..... | 33 |
| 2. A comparison of mountain biking and road cycling..... | 34 |
| D. A comparison of track cycling and road cycling | 38 |
| E. Conclusion | 40 |
| CHAPTER FOUR: INTERVENTION TRAINING FOR CYCLISTS | 41 |
| A. Introduction | 41 |
| B. Training the aerobic and anaerobic energy systems | 42 |
| 1. Training the aerobic energy system..... | 43 |
| 2. Training the anaerobic energy system..... | 45 |
| 3. Conclusion..... | 48 |

| | |
|---|-----------|
| C. The effect of endurance and interval training on cycling performance..... | 48 |
| 1. Submaximal endurance training..... | 49 |
| 2. High-intensity interval training..... | 50 |
| D. The effect of strength and power training on cycling..... | 55 |
| CHAPTER FIVE: PROBLEM STATEMENT..... | 60 |
| A. Background..... | 60 |
| B. Objective of the study..... | 60 |
| C. Specific aims..... | 61 |
| CHAPTER SIX: METHODOLOGY..... | 62 |
| A. Study design..... | 62 |
| B. Subjects..... | 62 |
| 1. Inclusion criteria..... | 62 |
| 2. Exclusion criteria..... | 63 |
| C. Experimental overview and procedure..... | 63 |
| D. Tests and measurements..... | 65 |
| 1. Kinanthropometry..... | 65 |
| 2. Vertical jump test..... | 67 |

| | |
|--|-----------|
| 3. Bench pull..... | 67 |
| 4. Aerobic capacity test..... | 68 |
| 5. 5-km time trial (TT)..... | 70 |
| 6. Anaerobic capacity test..... | 70 |
| 7. Field test..... | 71 |
| E. Intervention..... | 71 |
| F. Control group..... | 73 |
| G. Statistical analysis..... | 73 |
| CHAPTER SEVEN: RESULTS..... | 74 |
| A. Introduction..... | 74 |
| B. Subject characteristics..... | 74 |
| C. Maximal exercise capacity..... | 75 |
| 1. Experimental versus control group at baseline..... | 75 |
| 2. Road cyclists versus mountain bikers at baseline..... | 76 |
| 3. Effect of plyometric training on maximal exercise capacity..... | 76 |
| D. 5-kilometer laboratory time trial..... | 77 |
| 1. Experimental versus control group at baseline..... | 77 |
| 2. Road cyclists versus mountain bikers at baseline..... | 78 |
| 3. Effect of plyometric training on time trial performance..... | 78 |

| | |
|--|----|
| E. 30-second Wingate test | 79 |
| 1. Experimental versus control group at baseline..... | 79 |
| 2. Road cyclists versus mountain bikers at baseline..... | 80 |
| 3. Effect of plyometric training on Wingate performance..... | 80 |
| F. 4.4-kilometer field time trial | 81 |
| 1. Experimental versus control group at baseline..... | 81 |
| 2. Effect of plyometric training on field time trial performance..... | 81 |
| G. Strength and explosive power | 82 |
| 1. Experimental versus control group at baseline..... | 82 |
| 2. Effect of plyometric training on strength and power..... | 82 |
| H. Relationship between performance outcomes | 84 |
| CHAPTER EIGHT: DISCUSSION | 85 |
| A. Introduction | 85 |
| B. The reason why plyometric training can benefit cycling | 85 |
| C. Reflections on the findings of this study | 86 |
| D. Reasons for the limited effect of plyometric training | 89 |
| 1. Amount of sessions..... | 89 |
| 2. Types of exercises..... | 90 |
| 3. Time of season..... | 90 |

| | |
|-----------------------------------|------------|
| 4. Sample size..... | 90 |
| 5. Outcome variables..... | 91 |
| 5.1 Vertical jump test..... | 91 |
| 5.2 Bench pull test..... | 92 |
| 5.3 Laboratory cycling tests..... | 92 |
| 5.4 Outdoor time trial..... | 93 |
| E. Conclusion..... | 93 |
| REFERENCES..... | 94 |
| APPENDIX A..... | 118 |
| APPENDIX B..... | 124 |
| APPENDIX C..... | 125 |
| APPENDIX D..... | 128 |

LIST OF FIGURES

| | | |
|-----|---|----|
| 6.1 | The sequence of pre- and post-intervention testing..... | 69 |
| 7.1 | The effect of the intervention program on (a) VO_{2max} , (b) peak power output, (c) VO_2 at lactate threshold and (d) maximal blood lactate concentration..... | 82 |
| 7.2 | The effect of the intervention program on (a) time and (b) average heart rate during the 5-kilometer laboratory time trial..... | 84 |
| 7.3 | The effect of plyometric training on the (a) peak power output and (b) mean power output from before to after the intervention ($p > 0.05$)..... | 86 |
| 7.4 | The effect of plyometric training on outdoor time trial performance ($p > 0.05$)..... | 87 |
| 7.5 | The effect of plyometric training on (a) bench pull and (b) vertical jump performance..... | 88 |
| 7.6 | Correlations between the (a) indoor and outdoor time trial time, (b) outdoor time trial (time) and indoor time trial (watts), and the (c) outdoor time trial and the bench pull test..... | 89 |

LIST OF TABLES

| | | |
|-----|---|----|
| 2.1 | The different types of lower-body plyometric drills (from Potach and Chu, 2000)..... | 15 |
| 2.2 | The different types of plyometric warm-up drills (form Potach and Chu, 2000)..... | 18 |
| 3.1 | The maximal exercise capacity of the mountain bikers and the road cyclists (Lee <i>et al.</i> , 2002)..... | 38 |
| 3.2 | The time trial performance of the mountain bikers and the road cyclists (Lee <i>et al.</i> , 2002)..... | 38 |
| 7.1 | Personal characteristics of the experimental and control groups during baseline testing ($p > 0.05$)..... | 79 |
| 7.2 | The maximal exercise capacity of the experimental and control group during baseline testing ($p > 0.05$)..... | 80 |
| 7.3 | The maximal exercise capacity of the mountain bikers and the road cyclists during baseline testing ($p > 0.05$)..... | 81 |
| 7.4 | 5-kilometer laboratory time trial performance of the experimental and control group during baseline testing ($p > 0.05$)..... | 83 |
| 7.5 | 5-kilometer laboratory time trial results between the mountain bikers and the road cyclists during baseline testing..... | 83 |
| 7.6 | The anaerobic capacity of the experimental and control group at baseline testing ($p > 0.05$)..... | 84 |
| 7.7 | The anaerobic capacity of the mountain bikers and the road cyclists during baseline testing ($p > 0.05$)..... | 85 |

CHAPTER ONE

INTRODUCTION

Optimal cycling performance requires both power (speed) and endurance, and cyclists are increasingly expected to perform with both aerobic and anaerobic energy systems (Gregor and Conconi, 2000). The challenge remains to train these systems during the same phase of the season, and not to compromise either strength or endurance when the competition phase arrives. Coaches and trainers are under pressure to think creatively about training methods and strategies to optimise performance, without affecting the basic component, endurance capacity, negatively.

Since the introduction of power cranks in cycling, more emphasis is placed on power training, and the result is that there is very little differences among the top cyclists in the world. Top sprinters and mountain bikers, specifically, will always try to improve their power, improving their overall performance and their ability to produce power in a very short period of time. When training for power in sport like athletics, basketball and volleyball, plyometric training has been used successfully to improve the jumping ability, and thus leg power of these athletes.

In cycling, however, power training is mostly limited to bike training with power cranks, and in some occasions, strength training in the gymnasium. Normally this type of strength training on the bike is very limited in variation. Gymnasium training may lead to an increase in overall leg strength, but is rarely cycling specific. The improved leg strength does not necessarily improve a cyclist's ability to accelerate in a very short period of time, which is an important requirement in mountain biking. Therefore, improving the muscle's ability to produce maximal power in a short period of time, i.e. through plyometric training, might improve the cyclist's performance.

The effects of plyometric training have been studied in a variety of sport, most notably those sport that require short bursts of high intensity exercise and explosive power. Only one study, recently done by Paton and Hopkins (2005), studied the effect of

combining an explosive and a high-resistance training program on the performance of competitive cyclists. The study showed signs of enhancements in endurance and sprint performance, although they concluded that further research is needed to investigate the relative contribution that this type of training has on the overall performance of cyclists.

By including a progressive plyometric training program into the preparatory phase of mountain bikers and road cyclists' season, cyclists might improve their power and endurance without disrupting their normal training. Therefore, in the present study, certain physiological and performance aspects were investigated to determine whether plyometric training might translate to improved cycling performance. It was also important to determine if plyometric training have any detrimental effects on the aerobic capacity of cyclists.

By combining the correct type of explosive plyometric exercises, training the same muscles that are used during cycling, there is no obvious reason why plyometrics cannot improve cycling performance in some way.

CHAPTER TWO

PLYOMETRIC TRAINING

A. What is plyometrics?

Plyometric exercises are quick, powerful movements which enables a muscle to reach maximal force in the shortest possible time (Chu, 1998). This is done by using a prestretch, or countermovement, which includes a stretch-shortening cycle (SSC). Plyometric exercise increases the power of subsequent movements by using the elastic components of muscle and tendon, and the stretch reflex (Potach and Chu, 2000). It reduces the time required for voluntary muscle contraction, resulting in faster movement direction changes (i.e. agility). It has also been observed that plyometric exercise improves the production of muscle force and power, which includes using active muscles at speed during a functional movement. The effect of plyometrics can be explained by Newton's Second Law: $Force = mass \times acceleration$, where acceleration, specifically, can be increased through plyometric training.

According to Siff and Verkhoshansky (1999) the term plyometrics first appeared in a Soviet publication. Apparently Russians used this form of training since the early 1960's, where Verkhoshansky (from the State Central Institute of Sports Science in Moscow) used it as a "Russian training secret", to improve the speed-strength capabilities of Soviet athletes (Siff, 2000). They used the term "shock treatment". Later this type of training was implemented in western countries and gradually spread all over the world. Today it is commonly used in athletics, basketball and many other sports with ballistic movements. It has been shown that plyometric training, or a combination of plyometric training and a sport specific training program, have an acute and chronic advantage on exercise and exercise training over a short period of time. The acute improvements include an increase in one-repetition maximal leg strength and a delayed onset of muscle soreness. Chronic improvements include an increase in explosive power, flight time and maximal isotonic and isometric leg muscle strength, isokinetic peak torque of the legs and shoulders, average leg muscle

endurance, range of ankle motion, speed, and electrical muscle activity. It also decreases ground contact time during sprinting actions, and amortization time during plyometric exercises (Coetzee, 2007).

From the literature it is apparent that plyometric training has been successful in improving speed (Pettitt, 1999), explosive power (Potach and Chu, 2000; Bender, 2002), explosive reactivity (Archer, 2004), and eccentric muscle control during dynamic movements (Prentice, 2003).

B. The physiology of plyometric training

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

1. The mechanical model

The mechanical model explains that during eccentric muscle movement the elastic energy in the musculotendinous components increases with a rapid stretch and that this elastic energy is then stored. When this is immediately followed by a concentric muscle action, the stored elastic energy is released. The series elastic component (SEC) plays a very important role in this model (Coetzee, 2007). The SEC consists of muscle parts that do not contract when a muscle contracts against a load (Guyton and Hall, 2000), and includes the tendons and the cross-bridging characteristics of actin and myosin that shape muscle fibers (Chu, 1998). This SEC increases the total amount of force produced during the muscle action (Hill, 1970) and therefore results in greater explosive power. To maximise the power output of the muscle, the eccentric muscle action must be followed immediately with a concentric muscle action (Radcliffe and Farentinos, 1999; Potach and Chu, 2000). If the eccentric muscle action is not immediately followed by a concentric muscle action, the stored energy dissipates and is lost as heat (Potach and Chu, 2000; Voight and Tippett, 2001).

2. The neurophysiological model

The neurophysiological model involves the potentiation (when the contractile components' force-velocity characteristics changes with a stretch) of the concentric muscle action by using the stretch reflex. The stretch reflex is the body's involuntary response to an external stimulus that stretches the muscle (Potach and Chu, 2000). Muscle spindles are one of the spiral receptors that play an important role during the stretch reflex (McArdle *et al.*, 2001) and are located in parallel with the muscle fibers (Voight and Tippett, 2001). Muscle spindles consist of small bundles of specialised skeletal muscle fibers and are very sensitive to the rate and size of a stretch. When a muscle is rapidly stretched, it stimulates the muscle spindle, which causes a reflexive muscle reaction. This reflexive muscle action increases activity of the agonist muscle, and increases the amount of force produced during the concentric phase of the movement (Potach and Chu, 2000). McArdle *et al.* (2001) also explained that the rapid lengthening phase in the stretch-shortening cycle produces a more powerful subsequent movement. This is because of a higher active muscle state (greater potential energy) before the concentric muscle action, and a stretch-induced evoking of segmental reflexes that potentiate subsequent muscle actions.

3. The stretch-shortening cycle model

The stretch-shortening cycle (SSC) uses the energy storing capacity of the SEC, and stimulates the stretch reflex to facilitate a maximal increase of muscle recruitment over the shortest possible time (Potach and Chu, 2000). The SSC can be defined as the basic muscle function, where the preactivated muscle is firstly stretched (eccentric action), and then followed by a shortening (concentric) muscle action (Nicol *et al.*, 2006). There are certain prerequisites for an effective SSC, which includes accurate timing of muscle activation before the eccentric movement, and a short and rapid eccentric movement with an immediate changeover to the concentric phase (Voight and Tippett, 2001; Komi, 2003). During muscle activation neural control plays a very important role (Nicol *et al.*, 2006), as a specific neuromuscular activation is required

to activate the eccentric movement. To gain muscular strength and size in the muscle, this training stimulus must be consistently repeated over a period of time (Kraemer, 2000).

The SSC are divided into three different phases, namely the eccentric phase, the amortisation phase, and the concentric phase. Phase one, the eccentric phase, involves the preloading of the agonist muscle group. During running or hopping, there is a great amount of impact with the ground. Therefore the lower-limb muscles must be preactivated to prepare them for this impact (Nicol *et al.*, 2005). The SEC stores elastic energy while the muscle spindles are stimulated (Potach and Chu, 2000; Voight and Tippett, 2001). The contractile and tensile elements are stretched during this eccentric phase (Nicol *et al.*, 2006). When the muscle spindle stretches, it sends a signal to the ventral root of the spinal cord, using Type Ia afferent nerve fibers. During amortisation, the second phase, the afferent nerve fibers synapses with the alpha motor neurons and this causes the delay between the first (eccentric phase) and the third phase (concentric phase). The alpha motor neurons then transmit signals to the agonist muscle group. The shorter the amortisation phase, the greater is the subsequent force production. During the concentric phase the body responds to the first two phases. When the neurons stimulate the agonist muscle, it results in a concentric muscle action (Potach and Chu, 2000). Most of the force that is produced comes from the fiber filaments sliding over each other (Voight and Tippett, 2001). The energy stored during the eccentric phase is used to increase the force produced during the subsequent movement, and adds up to the force produced during the isolated concentric muscle action (Potach and Chu, 2000).

C. Muscle physiology during exercise

The benefits of plyometric training on improved muscular performance are believed to be essentially attributable to altered patterns of muscle activation (Chimera *et al.*, 2004; Malisoux *et al.*, 2006b), faster force development and neural activation (Hakkinen *et al.*, 1990).

For a muscle to go into a concentric or an eccentric phase, there are certain chemical and mechanical changes that have to take place within the muscle fiber that will enable the muscle to change its muscle length. This is where calcium (Ca^{2+}) plays a very important role in regulating the muscle fiber's contractile and metabolic activity (McArdle *et al.*, 2001). During resting conditions Ca^{2+} is stored in the lumen of the sarcoplasmic reticulum. When an action potential from a motor nerve signals that Ca^{2+} must be released into the myofibril, gated Ca^{2+} channels allow the high concentration Ca^{2+} within the lumen to pour into the myofibril (Mathews and van Holde, 1990). The calcium binds with troponin and other proteins in the actin filaments. Therefore the inhibitory action of the troponin–tropomyosin (which prevents actin-myosin interaction) dissipates, and the muscle “turns on” for action (McArdle *et al.*, 2001).

To determine the effect of plyometric exercises on calcium sensitivity, and the influence of Troponin T isoforms on calcium activation properties in single muscle fibers, Malisoux *et al.* (2006b) studied biopsies obtained from the *Vastus Lateralis* muscle before and after an eight-week plyometric training program (three sessions per week, lasting between 20 and 45 minutes). Eight healthy men, who were involved in regular exercise or physical activities (training approximately three hours per week), were used in the study. They were instructed not to change their daily activity pattern during the study period. Chemically skinned muscle fibers were evaluated in terms of its Ca^{2+} -activation properties, and classified according to its myosin heavy chain (MHC) contents. It was then analysed for their slow and fast Troponin T isoforms. The majority of the muscle fibers contained Type I, Type IIa or Type IIa/IIx myosin heavy chains. Leg strength and power were measured with the vertical jump tests (standard jump and the countermovement jump), the leg press test (one-repetition maximal force), and the time to perform a 6 x 5-m shuttle run test. After the plyometric training, subjects performed significantly better in both the standard vertical jump and the countermovement jump tests. They also improved their performance in the leg press test and the 6 x 5-m shuttle run test. The type I single-fiber diameter increased by 11%, 10% in type IIa, and 15% in type IIa/IIx fibers. This

increase in muscle fiber diameter typically occurs after resistance training (Widrick *et al.*, 2002). The peak fiber force increased by 35% in type I, 25% in type IIa, and 57% in type IIa/IIx fibers. Fiber force increased in all fiber types, confirming previous findings (Malisoux *et al.*, 2006a) and was probably the result of the increase in fiber diameter (Widrick *et al.*, 2002). The Ca^{2+} concentration needed to perform a half-maximal activation, generally decreased, with a significant reduction in type I fibers. As plyometrics is characterized by high-velocity eccentric muscle contractions of the muscle, it was assumed that type II MHC would respond best to this type of training. This study showed the opposite, as type I MHC was most responsive to the training stimuli. The explanation for this might be that type I fibers have a greater functional plasticity in its response to training compared to type II fibers. The main finding of this study, however, is that plyometric training increases Ca^{2+} sensitivity of muscle fibers. Malisoux *et al.* (2006b) not only confirmed their previous findings (Malisoux *et al.*, 2005) but also confirmed that plyometric exercise enhances the structural and functional capabilities in single muscle fibers.

Kyröläinen *et al.* (2005) found that 15 weeks of maximal-effort power training showed no significant changes in muscle-fiber type or size (which is contradictory to the above research), and reasoned that the enhancements in jumping performance was because of improved joint control and rate of force development at the knee joint. In this study, however, plyometric training was only performed twice a week, with a lower exercise volume, and involved athletes who were already more active (training approximately six hours per week). Therefore, the results might not be as evident as in the study done by Malisoux *et al.* (2006b).

With plyometric exercises, a high level of eccentric force is required to stabilise and control the knee and hip joint. Furthermore, a high level of concentric *Quadriceps* and *Hamstring* muscle force development is needed for momentum during all of the movements. To determine the effect of plyometric training on the *Hamstring* and *Quadriceps* muscles, Wilkerson *et al.* (2004) studied the neuromuscular changes in 19 collegiate woman basketball players. They followed a six-week plyometric jump-

training program as part of their preseason-conditioning program. The isokinetic peak torque of the *Hamstring* and the *Quadriceps* muscle groups were measured before and after the training program at $60^{\circ}\cdot\text{s}^{-1}$ and $300^{\circ}\cdot\text{s}^{-1}$. The experimental group ($n = 11$) participated in stretching, isotonic strengthening and constructed plyometric training under the investigator's supervision. The control group ($n = 8$) also participated in stretching, isotonic strengthening and a periodic performance of unstructured plyometric exercises done under supervision of their coaches. Data were collected from the *Quadriceps* and *Hamstring* muscles during a forward lunge test, called the unilateral step-down test. Results showed a significant increase in the *Hamstring* peak torque at $60^{\circ}\cdot\text{s}^{-1}$ in the experimental group, while only three of the eight subjects in the control group showed an increase. The *Hamstrings* did not show a significant increase at $300^{\circ}\cdot\text{s}^{-1}$ for the experimental group. There was no significant increase in the *Quadriceps* muscle's torque at either the $60^{\circ}\cdot\text{s}^{-1}$ or $300^{\circ}\cdot\text{s}^{-1}$ isokinetic test velocities. This study shows that the plyometric training increased the performance capability of the *Hamstring* muscle, but not the *Quadriceps* muscles. The improvement in the *Hamstring* muscle's strength stabilises and controls the eccentric movement during hip and knee motion.

Eccentric movement in the *Hamstring* muscles takes place during running and jumping movements, and also has a role to play during the pedal cycle in cycling (Gregor and Conconi, 2000). Therefore, any increase in the *Hamstring* muscle's strength, will have a positive affect on the performance of athletes in most sports where controlled movement of the hip and knee joint is required.

Plyometric training not only influences the performance of muscles during all types of movements, it also has an influence on the bone mass. Physical activity that generates a high intensity loading force (for example, plyometrics, gymnastics and high-intensity resistance training) has a positive effect on bone health across the age spectrum, by increasing bone mass and strength (Kohrt *et al.*, 2004).

Witzke and Snow (2000) found that plyometric jump training affects bone mass in adolescent girls. 25 high school girls followed a nine-months plyometric program, training three times a week during a physical education class. A control group (n = 28) continued with their normal program (including sports like basketball, volleyball, softball and track training). Bone mineral content (BMC), muscular strength, muscular power, and static balance were measured before and after the intervention. BMC was measured by dual x-ray absorptiometry. Isokinetic strength of the left knee extensors was measured, while maximum muscle power of the lower extremities was determined by a Wingate anaerobic test on a cycle ergometer. The Biodex Stabilometer was used to determine static balance.

Results showed that trochanteric BMC improved statistically significantly, while leg strength and balance improved over the nine months intervention, but these improvements were not significantly different from the control group. Although the experimental group showed an overall trend of improvement in bone mass, the only statistical significant increase was found in the greater trochanter. These results could have been influenced by the fact that the control group performed much better during baseline testing than the experimental group and were overall (before and during the study) more physically active than the experimental group.

Blimkie *et al.* (1996) also found no statistical significant improvements in bone mass, content or density after six months of strength training in adolescent girls, although there was a positive trend towards increasing bone mass. Exercises were done three times a week, performing four sets of 12 repetitions, on hydrolic resistance machines. These results show that physical activity, including plyometrics, has a positive effect on bone mass and health, even if it does not significantly improve the BMC.

Plyometric movement includes the body as a whole. While the *Quadriceps* and *Hamstring* muscle groups play a major part in the jumping movement, the trunk muscles are very important for stability, support, and they absorb a lot of the impact. The trunk and all its muscles may therefore also benefit from plyometric exercise. To

determine the effect of plyometric on the muscular capabilities of the trunk, Kubachka and Stevens (1996) performed plyometric exercises on a group of subjects for five weeks. Trunk muscle power was measured by performing a sit-up-for-speed test. The results showed a significant increase (8.6%) in the plyometrics group, and indicate that plyometric exercise can be used to improve the muscle power of the trunk.

The effects of upper body plyometrics on the posterior shoulder and the elbow of men and woman were studied by Schulte-Edelmann *et al.* (2005). A plyometric training group (n = 13) performed two upper-body plyometric sessions per week over a period of six weeks. The control (n = 15) group did no plyometric exercises, and was also instructed not to participate in any upper-body strength training during this period. Isokinetic testing was performed to determine peak power output in the elbow extensors, and in the shoulder internal and external rotators. The peak power was determined by using an isokinetic dynamometer. The experimental group showed significant gains in elbow extensor power, but there were no significant differences between the experimental and control groups in terms of the peak power output of the external and internal shoulder rotators.

Previous studies done by Wilk *et al.* (1993 and 1994) and Heiderscheit *et al.* (1996) suggested that the upper-body responds in the same way to plyometric training than the lower extremities. Heiderscheit *et al.* (1996) reported no significant improvements in the shoulder, similar to the study done by Schulte-Edelmann *et al.* (2005). This may be due to the lower muscle mass in the upper-extremity, and that these muscles were not properly overloaded during the intervention. The shoulder muscles have a greater cross-sectional area in the muscles compared to the elbow extensors. Schulte-Edelmann *et al.* (2005) might only have overloaded the elbow extensors during plyometric training, therefore only the power in the elbow extensors showed a significant increase, and not the shoulder rotators.

Although most studies have shown that motor and physical components are responsible for improvements in power after plyometric training, some studies have

shown that peripheral changes may also have an influence (Coetzee, 2007). Potteiger *et al.* (1999) found that an eight-week plyometric program resulted in a 7.8% improvement in fibre diameter in the concentric activated muscle fibers. Spurrs *et al.* (2003) found an increase in musculotendinous stiffness in the lower legs after plyometric training, which is an example of a peripheral change. Musculotendinous stiffness facilitates explosive power production by increasing the length and tempo of shortening (Wilson *et al.*, 1994).

In contrast to all of the above research, Hutchinson *et al.* (1998) argued that plyometric training improves sports performance because of a cognitive learning effect. Hutchinson *et al.* (1998) used jump training to improve the leaping ability of six elite rhythmic gymnasts, and also included a control group consisting of two subjects. Testing included reaction time, leap height and explosive power, and was performed on a force plate. Testing was done before the intervention, after one month of training, and after an additional three months of training. Three athletes were also retested after one year of maintenance protocol training, although they also continued intense training for an international competition. The athletes underwent jump training, which included pool training (one hour, twice a week), and participated in Pilates' classes (twice a week during the first month, and once a week thereafter). After one month of training, the experimental group improved their leap height by 16.2%, their ground reaction time by 50% and explosive power by 220%. After three months of continued maintenance training, there were no further significant improvements in any of the tested variables. The control group showed no significant changes after the first month, or the additional three months. The three subjects, who were retested after one year, showed that their initial gains were maintained. Because there were no additional achievements from the pretraining levels after one year, Hutchinson *et al.* (1998) supports the hypothesis that jump training is more likely a cognitive, learned outcome rather than simply a motor strengthening effect.

D. Designing a plyometric training program

In the design of a plyometric program, it is important to keep in mind the level of training the athlete is currently at. As with any training program, a plyometric program starts with a period of preparation, and move into time frames with more specific goals (Chu, 1998). Because plyometric training involves a lot of ground contact, the athlete must have a certain level of strength before he/she starts with a plyometric program. The mode, intensity, frequency, volume and recovery are important factors to keep in mind when designing the training program. The combination of program length and progression will determine the degree of performance enhancement of the athlete (Potach and Chu, 2000).

1. Mode

The mode of plyometric training is determined by the major muscle group(s) involved in the specific type of sport, and therefore specificity is important to keep in mind. For instance, in mountain biking and road cycling the lower body are the most important, although the upper body is also involved to a certain degree. There are three different modes of plyometric exercise:

Lower-body plyometrics

Most sports require a maximal amount of muscular force in the shortest possible time, therefore most athletes, irrespective of sports code, engage in lower-body plyometric training. Lower-body training can be used to improve vertical, horizontal and lateral movements, and specifically to change direction. There is a wide variety of lower-body plyometric drills, and those are divided into various types of jump movements. Table 2.1 describes these different types of lower body drills.

Table 2.1 The different types of lower-body plyometric drills (from Potach and Chu, 2000).

| Type of Jump | Rational |
|-------------------------|---|
| Jumps in Place | Jumps in place involve jumping and landing in the same spot. These drills put emphasis on the vertical component of jumping. It is performed continually without rest between jumps. |
| Standing Jumps | Standing jumps lay emphasis on either horizontal or vertical components. These drills are maximal efforts and allow enough recovery between repetitions. |
| Multiple hops and jumps | These drills involve repetitive movements. It may be viewed as a combination of multiple jumps in place and standing jumps. |
| Bounds | These drills involve exaggerated movements, and put an emphasis on greater horizontal speed than the other drills. |
| Box Drills | By using a box, these drills increase the intensity of multiple hops and jumps. The box may be used to either jump on to, or to jump from. |
| Depth Jumps | By using the athlete's weight and gravity, these drills increase the intensity of the exercise. The athlete assumes a position on box, steps off, lands, and immediately jumps vertically, horizontally, or to another box. |

Upper-body Plyometrics

Although upper-body plyometrics are not used as often as lower-body plyometrics, there are several sports that require a rapid and powerful upper body movement. By training the shoulder and the elbow joint, it increases upper body power in sports like baseball, shot put, discus, tennis and golf. Upper-body plyometrics includes exercises like medicine ball throws and different types of push-ups (Potach and Chu, 2000).

Trunk Plyometrics

The torso area (muscles in the mid-section of the body) of the body links the upper body with the lower body, and it plays a very important role during all types of sport-specific movements. A strong torso helps an athlete to have a strong platform to perform his or her movements from. It assists in developing power and improving coordination in muscle groups (Boyle, 2004). By performing plyometric movements that improves the functional ability of the trunk and the abdominal muscles, it will assist in performing powerful movements.

2. Intensity, frequency and duration

Plyometric intensity refers to the amount of stress placed on the active muscle during the plyometric drill. Each plyometric exercise can be categorised according to the intensity level (Young, 1991). The intensity level, or level of stress involved in the movement, can be modified through a few factors. For instance, by increasing the speed of the movement, the intensity of the exercise is increased. By increasing the height of the box with a box drill, it elevates the body's center of gravity, and therefore increases the landing force. Single leg exercises increase the ground reaction force of a movement, and places more stress on the joints, muscles, and connective tissues involved (Voight and Tippett, 2001).

When determining the training frequency, it is important to keep in mind the type of sport and the time of the year for the athlete (transition phase). Training sessions typically range from two to four sessions per week, allowing 48 to 72 hours recovery between sessions (Potach and Chu, 2000), although intensity plays a major role when determining training frequency (Voight and Tippett, 2001). Some sports only require two sessions per week and will only use plyometric training during the transition phase. Other sports will find plyometric training more demanding, and use this type of training throughout the season and for up to four times a week. Because plyometric drills require maximal efforts, complete and sufficient recovery is needed. Depth jumps require five to ten seconds of rest between repetitions, and two to three

minutes between sets. Normally plyometric training requires a 1:5 to 1:10 work-to-rest ratio, and is specific to the type of drill being performed. Drills must be seen as a power training method, and not a cardiovascular workout (Potach and Chu, 2000). During plyometric exercises, emphasis must be placed on the quality of the movement, and must be done at the beginning of the training session before any other type of exercises (Chu, 1998).

The number of sets and repetitions done during a training session are referred to as plyometric volume. The number of foot contact sessions with the ground, constitute the lower-body plyometric volume (Potach and Chu, 2000; Voight and Tippett, 2001). During plyometric bounds (exaggerated movements that emphasises horizontal distance), the volume can be expressed as the distance covered during the movement. When beginning a plyometric program, the volume should be between 80 and 100 foot contacts. For athletes with more experience, volume should be between 100 and 120, and it can progress up to 140 for advanced athletes. Typically, when the intensity of the exercise increases, the volume of the same exercise decreases. Plyometric programs usually ranges between six and ten weeks, although some programs have been as short as four weeks, and as long as 12 weeks. Again, the program length depends on the type of sport, and the time of the year (Potach and Chu, 2000).

In any training program progression over the entire training period is important. The success of the plyometric program depends on how the training variables, like intensity and volume, are controlled and adapted (Voight and Tippett, 2001). Therefore, to keep the athlete interested, the plyometric program must follow the progressive overload principle. This means a regular increase in volume, frequency, and intensity. Once again, the training phase of the year and the type of sport will influence the training method of progressive overload (Potach and Chu, 2000).

As with any other training session, a plyometric session starts with a warm-up, which consists of low-intensity, dynamic movements. The number of foot contacts during the

warm-up is not included when computing the volume of the plyometric session, therefore it is important not to overextend the athlete at the start of the session (Chu, 1998). Table 2.2 describes different types of plyometric warm-up drills.

Table 2.2 The different types of plyometric warm-up drills (from Potach and Chu, 2000).

| Drill | Explanation |
|----------|---|
| Marching | Marching is imitated running movements. This improves proper lower-body movements for running. |
| Jogging | Jogging prepares the athlete for impact and high-intensity plyometric drills. e.g. toe jogging, straight legged jogging, butt-kicking. |
| Skipping | Skipping is an exaggerated form of shared upper-and lower-extremity movements. |
| Footwork | Footwork drills target a sudden change of direction. |
| Lunging | This drill is based on lunges, and can also be multi-directional. |

E. The effect of plyometric training on performance in various sports

Since plyometric training has been accepted as a training modality in western countries, most sports trainers have employed this type of training to increase the muscle power in their athletes. As a result a lot of research have been done over the past few years to determine the performance effects of plyometric training. Coetzee (2007) found that most of the research were done on recreationally active individuals (i.e. low activity levels) and not on elite athletes. Various sports have used plyometric training as part of their regular training program. Ebben (2002) found that by combining weight training and plyometric training in an efficient way (during the same session), muscular power and athletic performance could be improved. However,

research on athletes have shown improvements in performance over a wide spectrum of sports including athletics, golf, swimming, basketball and running.

To determine the effects of plyometric training on athletic performance, Villa *et al.* (2007) measured a variety of variables including sprint time, agility, vertical jump, standing-broad jump, one repetition maximal (1RM) squat, flexibility, body composition, and waist, hip, thigh, and calf girth. The subjects included 10 healthy low-risk college students. Plyometric training was performed twice per week, for eight weeks. Results showed a much lower (19.22 ± 8.39 versus 17.47 ± 7.82) body composition (fat percentage), with a greater waist and hip girth, and a significantly decreased thigh girth. Performances in the standing broad jump, vertical jump, and the 1 RM squat increased significantly, while the calf girth, sit-and-reach flexibility, 20-meter sprint time, and the agility run time showed no improvements. This study showed that a progressive plyometric program can improve body composition, and also induce hypertrophy in the abdominal and hip flexor muscles. What may be important for long- and high jumpers is that plyometric training can improve both vertical and horizontal jumping ability.

Rimmer and Sleivert (2000) studied the effects of a plyometric program on sprinting performance. 26 subjects, consisting of 22 rugby players and four touch rugby players (loose forwards and backline players), all playing at under 21 or elite level were included in the study. The subjects were divided into a plyometrics group ($n = 10$), performing sprint-specific plyometric exercises, a sprint group ($n = 7$), performing sprints, and a control group ($n = 9$). All three groups completed sprint tests before and after the eight-week intervention (15 sessions), performing three to six maximal sprint efforts between 10 and 40 meters. During the 40-meter sprint, time was also recorded at 10-, 20-, 30-, and 40-meter marks. The stride frequency in the 10 and 40-meter sprints were also determined with a video camera. Ground reaction time was measured with a force platform between the seven and the 10-meter mark, and between the 37- and 40-meter mark. The plyometrics group showed a significant decrease in time over 0-10, and 0-40 meters, with the greatest improvement within

the first 10 meters of the sprint. However, these improvements were not significantly different from the sprint group. The control group showed no improvements in sprint time. There were no significant changes in stride length or frequency for any of the groups during the entire study. The plyometrics group was the only group to show a significant decrease (4.4%) in ground reaction time, and this was between the 37- and 40-meter mark. These results show that sprint-specific plyometric exercise can improve sprint performance to the same extent as regular sprint training, especially over the first 10 meters (acceleration phase) of the sprint. This might be because of a shorter ground reaction time. Sports where speed for up to 40 meters are important, might benefit in adding sprint-specific exercises to the regular sprint training program, especially when acceleration adds to improved performance.

Not only has plyometric training been used to improve short distance running or sprints, it also has a role to play in long distance running. Spurrs *et al.* (2003) studied the effects of plyometric training on distance running economy in 17 male subjects (running an average of 60 to 80-kilometers every week). The running economy, aerobic power (VO_{2max}) and lactate threshold of the experimental ($n = 8$) and control group ($n = 9$) were tested before and after a six-week plyometric program. Running economy was determined by a treadmill test starting at $10 \text{ km}\cdot\text{h}^{-1}$ for three minutes, and increasing the speed in increments of $2 \text{ km}\cdot\text{h}^{-1}$, after allowing one minute for the lactate measurement. After a speed of $20 \text{ km}\cdot\text{h}^{-1}$ was reached, a two percent gradient increase was added with each speed increment. The test progressed until the subject could no longer maintain the treadmill velocity. Running economy was calculated as the average VO_2 values during the last minute of the 12, 14, and 16 $\text{km}\cdot\text{h}^{-1}$ velocities. Subjects also had to complete a 3-kilometer time trial. The plyometric training intervention included two sessions per week for the first three weeks, and three times a week for the last three weeks. Results showed that plyometric training improved the subjects' 3-kilometer time trial performance with 1.6% from 10.28 ± 1.26 to 10.12 ± 1.15 minutes. Running economy increased with 6.7% at 12 (from 26.05 ± 4.11 to $24.30 \pm 3.68 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), 6.4% at 14 (from 33.35 ± 5.15 to $31.23 \pm 4.27 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), and 4.1% at 16 $\text{km}\cdot\text{h}^{-1}$ (from 41.96 ± 6.14 to

40.22 ± 5.43 mL·kg⁻¹·min⁻¹). There were no significant changes in VO_{2max} or lactate threshold in the experimental group, and therefore it was speculated that the improved performance during the time trial was due to the improvement in running economy.

The findings of Spurr *et al.* (2003) were confirmed by Saunders *et al.* (2004). After a nine-week plyometric program the running economy of highly trained distance runners improved by 4.1% at a treadmill running velocity of 18 km·h⁻¹. Running economy can be defined as the steady state oxygen (VO₂) requirement during a submaximal intensity exercise (Conley *et al.*, 1981; Morgan *et al.*, 1989). Previous research have shown that running economy is one of the best indicators of running performance (Conley *et al.*, 1984; Noakes, 1991; Daniels, 1998) and therefore these findings may have significant implications for those athletes who seek alternative training methods to enhance their performance.

In some studies it have been shown that plyometrics improve vertical jump performance (Matavulj *et al.*, 2001; Hammett and Hey, 2003; Luebbers *et al.*, 2003; Malisoux *et al.*, 2005; Markovic, 2007), while others have not found any significant improvements (Turner *et al.*, 2003; Chimera *et al.*, 2004). This may be because of a difference in training programs in terms of intensity or volume, as well as the possibility that the training program was not specifically designed to improve leg power. It is also possible that the vertical jump test is not sensitive enough to detect small, but significant changes in leg power. Vertical jumping height plays an important role in sports like high jump (athletics), volleyball and basketball.

Martel *et al.* (2005) used aquatic plyometric training (APT) to improve the vertical jump in female volleyball players (n = 19). Aquatic plyometrics have been shown to have similar or even better (Miller *et al.*, 2002; Robinson *et al.*, 2004) effects than land-based plyometrics. A further advantage is that APT has a lower potential for acute muscle soreness and musculoskeletal injury because of the buoyancy of water compared to regular plyometric training (Martel *et al.*, 2005). Subjects from a local

high school followed APT training twice a week for six weeks (45 minutes per session) together with their regular preseason volleyball training. Another group (control group) performed whole body flexibility training (twice a week, for six weeks) and a regular preseason volleyball program. Vertical jumping height was tested before the intervention, as well as after two, four and six weeks. After four weeks, vertical jump height improved by 3.1% in the APT group and 4.8% in the control group. After six weeks, the experimental group increased their performance by a further 8%, while the control group showed no further improvement.

Leubbers *et al.* (2003) found in their study an initial decline in vertical jumping height directly after completing a plyometric program, however, after four weeks of recovery, the subjects' performance increased significantly by 2.8% (from 67.8 ± 7.9 to 69.7 ± 7.6 centimeter). These results suggest that plyometric training can have a positive effect on sports where leg power is important, especially if such a program is combined with regular preseason training.

Fletcher and Hartwell (2004) studied the effect of a combined weight and plyometric training program on the golf driving performance of eleven male club golfers. The golfers' driving distance and club head speed were measured before and after the training program. The experimental group ($n = 6$) trained twice a week for 90 minutes over an eight-week period, and exercises included free weight exercises (bench press, squat, single arm row, lunges, shoulder press, upright row, abdominal crunches, back extension and side bends) and specific medicine ball exercises. The control group ($n = 5$) continued with a regular training program, which consisted mainly of aerobic exercises with light machine weights. The experimental groups' driving distance and club head speed showed a significant increase after the eight week weight training and plyometric program, while the control group showed no significant improvements. It was suggested that the weight training increased the muscle force through an increase in muscle cross-sectional area, and by improving motor unit recruitment. The plyometric exercises increased the power of the muscles

involved with the golf swing. Combining these types of training methods increased the golfers' ability to hit the ball further, and improve their overall driving performance.

In many sports trainers and athletes will include plyometric exercise in their regular training program. This type of combination training was therefore also the subject of a few research studies. Vossen *et al.* (2000) compared the effects of dynamic push-up training and plyometric push-up training on upper-body power and strength. The dynamic push-up (DPU) group (n = 17) and the plyometric push-up (PPU) group (n = 18) completed 18 training sessions over a six-week period, training three sessions a week. The subjects completed two tests, measuring the power and strength of the shoulder and chest, before and after the six-week intervention. The tests included the medicine ball put, and the one repetition chest pass. Although both groups performed significantly better in both tests, the PPU group demonstrated a significantly greater increase with the medicine ball put compared to the DPU group. The PPU group also showed a larger increase in the chest pass compared to the DPU group. These results show that the plyometric push-ups were more effective than the dynamic push-ups in improving upper-body strength and power. It remains to be seen whether these changes will translate into improvements in overall athletic performance.

It has been shown that plyometric training can improve performance in various sports, by either combining it with regular training or using it separately to improve a certain component of the physical requirements of the sport. In most sports it is being incorporated into preseason training and in combination with the usual preseason training program. It seems that plyometric training can be successfully employed to improve running speed, running economy and selected upper and lower body strength and power measures. All these fitness components are important for the majority of sports, albeit to varying degrees. Most studies, however, suggest that plyometric training may enhance overall athletic performance.

F. The effect of plyometric training on cycling performance

Most cycling events require a certain amount of endurance, as well as strength and explosive power. The effects of combined strength and endurance training have been the topic of many studies (Hennessy and Watson, 1994; Leveritt *et al.*, 1999; Gravelle and Blessing, 2000; Docherty and Sporer, 2000; Izquierdo *et al.*, 2005; Hamilton *et al.*, 2006) and to date conflicting reports have been published. In general, cyclists, especially road cyclists, do limited amounts of strength training, and this training usually happens in the off-season or pre-season.

However, the ability to generate high power outputs is often the most important determinant of cycling success. Therefore cyclists are required to perform some kind of resistance training to enhance explosive power and strength. High intensity interval training and resistance training are two specific training methods that have been studied in cyclists. Limited research are, however, available on the effects of plyometric training on cycling performance.

Paton and Hopkins (2005) studied the effects of a combined explosive and high-resistance training program on the performance of competitive cyclists (n = 18). While the control group (n = 9) continued with their regular cycling training, the experimental group (n = 9) replaced a portion of their regular training with explosive and high resistance exercises. The 12 sessions lasted for about 30-minutes each, and continued for four to five weeks, with two to three sessions per week. Sessions consisted of three sets of maximal effort single-legged jumps, and three sets of maximal intensity cycling efforts. Laboratory testing included an incremental cycle ergometer test to determine peak power output, and a submaximal test to determine blood lactate concentration and oxygen cost. One- and four-kilometer time trials were also completed and mean power was measured as the outcome variable.

While the control group showed a small change during all of the performance tests, the experimental group showed significant improvements in one-kilometer power

(8,7%), four-kilometer power (8.4%), peak power (6.7%), lactate-profile power (5.5%), and oxygen cost (-3.0%). These results thus show clear improvements in especially the time trials and the peak power, and to a lesser extent in the lactate profile and oxygen cost of the experimental group. There were no significant changes in the subjects' body mass in either the experimental or the control group. The study showed that by combining high resistance cycling with explosive exercises in already well-trained competitive cyclists, it increases the cyclists' exercise efficiency and aerobic power. This leads to improved sprint and endurance performance.

G. Conclusion

For effective training and performance optimisation, specific components of training (i.e. strength, endurance, speed and skill) must be trained either individually, or in combination. As most sports, including mountain biking and road cycling, require the development of some of the specific components, one needs to take cognisance of the potential negative effects of one training method on another component. For example, strength training has a strong negative impact on muscle mitochondria and thus endurance. From the available literature, it seems that plyometric training has no detrimental effect on endurance, or that an athlete can at least maintain a certain endurance level while incorporating plyometric training in their regular program.

CHAPTER THREE

PHYSIOLOGY OF CYCLING

A. Introduction

There are few sports that are as physically demanding as competitive cycling (Burke, 1986). Professional male road cycling competitions consist of one-day events, four to 10-day events, or even three weeks like the Tour de France, Giro d'Italia and the Vuelta a España (Mujika and Padilla, 2001). Cycling is therefore characterised as an endurance-based sport, although strength, power and speed are also important, and could be the determining factor in a winning performance. Track cycling events typically last between one and five minutes, while mountain biking and road cycling races last between two and four hours, and sometimes even longer. By changing the content and structure of a training program, it can have a lasting effect on a cyclist's performance in a specific event (Neumann *et al.*, 1992).

Usually an increase in riding speed is the result of an increase in pedaling rate and this determines the pedaling power. The latter can only be improved by training. However, not all the qualities of an athlete can be altered by physical training. Among the other variables that are important determinants of sport performance are body composition, proportion of muscle fibers (type I versus Type II), and psychological qualities (Neumann *et al.*, 1992). The International Cycling Union (UCI) has very strict regulations regarding the equipment used during cycling, so the best way of improving performance is by training the physiological abilities of the cyclist (Sallet *et al.*, 2006).

During cycling, muscles require energy to perform, and there are three systems (creatine phosphate, oxidative and glycolytic metabolism) that supply energy to working muscles. Both intensity and duration of exercise determine the type of energy system that is used. The phosphate system does not need oxygen and does not produce lactic acid, and supplies energy directly to the muscles (Janssen, 2001).

Adenosine triphosphate (ATP), which enables muscles to contract, gets broken down to adenosine diphosphate (ADP) and energy. This energy system only supplies energy for up to ten seconds and a maximum effort may therefore result in exhaustion within 10 seconds. The oxygen system (aerobic system) uses fats and carbohydrates (glycogen) to produce energy and exercise can be sustained for 60 to 90 minutes with the stored glycogen in the muscles. Fat utilization for energy occurs mainly at low to moderate intensity exercises, and fat stores are just about unlimited. However, it is known that well-trained athletes obtain more energy from fat metabolism during exercise and thus can spare their muscle and liver glycogen stores. When, during exercise, the body reaches a point where the oxygen supply is not enough for muscle functioning, anaerobic metabolism dominates and this leads to lactic acid accumulation. The onset of muscle fatigue correlates with muscle glycogen depletion and high levels of lactate in the blood. During a sprint (30 seconds) most of the energy is derived from phosphocreatine and anaerobic glycolysis and is thus accompanied by high lactate levels (Faria *et al.*, 2005).

For optimal performance, all the energy systems must be developed and enhanced. Therefore, coaches and sport scientists should have a sound knowledge and understanding of the energy cost of cycling and the involvement of the various metabolic components during different events. Only then will they be able to competently prescribe training programs, develop assessment protocols and monitor training.

B. Predictors of cycling performance

Cycling performance and cycling potential can be predicted by a number of laboratory-based measures and physiological factors (Padilla *et al.*, 1996; Mujika and Padilla, 2001; Faria *et al.*, 2005). These include VO_{2max} , the power output at the lactate threshold, the power-to-weight ratio, the percentage of type I muscle fibers, the maximal point at which lactate concentration reaches a steady-state, and the peak power output during a maximal cycling test (Faria *et al.*, 2005).

1. Maximal oxygen uptake (VO_{2max})

VO_{2max} refers to the maximum amount of oxygen used during exercise, and is limited by both oxygen delivery (central factors) and oxygen utilization (peripheral factors). VO_{2max} is a reliable indicator of the capacities of the respiratory, cardiovascular and muscular systems and their integrated function as a determinant of endurance performance (Coyle *et al.*, 1983; Londeree, 1986; Bassett and Howley, 2000).

Research has shown that successful professional cyclists have high VO_{2max} values, above $74 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, and that their onset of blood lactate accumulation (OBLA) occurs at around 90% of VO_{2max} (Faria *et al.*, 1989; Saltin, 1990; Coyle *et al.*, 1991; Lucia *et al.*, 1998; Fernández-García *et al.*, 2000). Padilla *et al.* (1999; 2000) found VO_{2max} values between 69.7 and $84.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in professional road cyclists with maximal heart rates between 187 and 204 beats per minute. These superior VO_{2max} values can be attributed to highly developed lungs, hearts and locomotor muscles, which lead to improvements in both oxygen delivery to the muscles, as well as oxygen utilization by the muscles.

Trained cyclists can ventilate larger amounts of air and their vital capacities are larger than untrained individuals. Both in the lungs and locomotor muscles there are larger networks of capillaries which enhance the diffusion of gases, while the locomotor muscles also have more and larger quantities of mitochondria and oxidative enzymes that will promote aerobic metabolism. With training, a cyclist's heart grows in size and musculature strength, and therefore develops a greater cardiac output. This ensures that a larger amount of oxygen-rich blood is delivered to the active muscles (Faria *et al.*, 2005).

Although VO_{2max} is a valid determinant of endurance capacity, VO_{2max} on its own is not considered a valid indicator of overall cycling performance. However, in combination with other performance indicators (e.g. blood lactate, power output and metabolic efficiency), it successfully predicts cycling performance (Faria *et al.*, 2005).

2. Cycling economy and efficiency

During competition, cyclists need to sustain high workloads for extended periods of time. Therefore, a cyclist needs to have high cycling efficiency (Faria *et al.*, 2005). This means that the cyclist will expend as little as possible energy, at the highest possible percentage of VO_{2max} . Sometimes this is referred to as cycling economy. Research has demonstrated that variations in economy can explain 65% of the variation in performance among a group of elite runners with similar VO_{2max} values (Costill *et al.*, 1973). This same relationship may be true for cyclists, since it is known that VO_{2max} is not a discriminating factor between elite and good cyclists. According to Horowitz *et al.* (1994) cycling economy depends greatly on the amount of type I muscle fibers in the *Vastus Lateralis* muscle, since these muscle fibers operate at a lower submaximal oxygen cost than type II fibers and have a high resistance to fatigue. This efficiency is thus a reflection of the increase in aerobic metabolism and related increases in muscle power output (Lucia *et al.*, 2002).

3. Mean and peak power output

Peak power output is usually determined during a maximal exercise test to exhaustion. Padilla *et al.* (1999; 2000) found maximal power output values (watts) ranging between 349 and 525, during a cycle ergometer test with four-minute increments in well-trained cyclists. This parameter has been shown to be a good predictor of endurance performance. Hawley and Noakes (1992) found a significant correlation ($r = -0.91$; $P < 0.0001$) between a 20-kilometer time trial and maximum watts during an incremental test. Similarly, the best laboratory predictor of uphill cycling performance, covering either one or six kilometers (performed on a treadmill, with a 6 or 12 percent gradient), was found to be the cyclist's relative mean power output during a Wingate test (Davison *et al.*, 2000).

The importance of the cyclist's ability to produce power was illustrated by the work of Lucia *et al.* (2000b). They measured the mean power output of cyclists during well-

known road cycling races and found average values in the region of 400 W over a 60-minute period. Data also suggest that a high power output to body mass ratio at maximal or near-maximal intensity is a prerequisite for competitive cyclists (Palmer *et al.*, 1999). Power-to-weight ratios of 5.5 and more have been suggested as minimum requirement for elite level cyclists (Faria *et al.*, 2005). This also further confirms the importance of body composition as a determinant of performance.

4. Lactate threshold

Blood lactate increases in a linear trend during incremental exercise, and the point where it increases non-linearly, is known as the lactate threshold. Hagberg and Coyle (1983) defined the lactate threshold (lactate one) as the intensity where there was a one $\text{mmol}\cdot\text{L}^{-1}$ increase in lactate above average lactate values, and that this was usually measured at 40 to 60% of $\text{VO}_{2\text{max}}$ in the general population. Cyclists' lactate and/or ventilatory thresholds are typically determined to describe their aerobic capacity (Lee *et al.*, 2002). In trained cyclists, the threshold is usually above 70% $\text{VO}_{2\text{max}}$, while values greater than 85% $\text{VO}_{2\text{max}}$ are typically reported for elite cyclists (Impellizzeri *et al.*, 2002; 2005b).

Power output at the lactate threshold has been shown to be an important variable in cycling performance (Bentley *et al.*, 1998; Coyle *et al.*, 1991). Coyle *et al.* (1991) have shown that the higher the lactate threshold, the longer a cyclist's endurance time. Therefore, the power output or VO_2 at lactate threshold is a strong predictor of endurance performance in trained cyclists with similar maximal aerobic power ($r = 0.96$). Bishop *et al.* (1998) actually suggested that lactate parameters can be better predictors of endurance performance than $\text{VO}_{2\text{max}}$ in trained cyclists.

Coyle *et al.* (1991) studied the physiological factors associated with elite endurance cycling performance. Cyclists were signed up according to their performance in a 40-kilometer time-trial, and grouped into an "elite national class" (group one, $n = 9$) and a "good-state class" (group two, $n = 6$). Cyclists completed a one-hour time-trial on a

cycle ergometer at their highest power output, as well as a VO_{2max} test. Lactate threshold occurred at $79.2\% \pm 1.1\%$ of VO_{2max} in group one, compared to $75.3\% \pm 1.5\%$ of VO_{2max} in group two. The “elite-national class” group was capable of cycling at $90\% \pm 1\%$ of VO_{2max} (346 ± 7 watts) with an average blood lactate value of seven $mmol.L^{-1}$ during the one-hour cycle test. The average power output during the one-hour test, showed a high correlation with VO_2 at lactate threshold. The authors also demonstrated that the lactate threshold can be used to separate “good” cyclists from “elite” cyclists. This was illustrated by the fact that the elite group had an 11% higher average power output than the “good” cyclists two during the one-hour test, with a 10% higher velocity during the 40-kilometer time trial.

Another lactate parameter that is often used in exercise physiology, is the so-called four $mmol.L^{-1}$ threshold. This threshold has been termed the onset of blood lactate accumulation (OBLA) and occurs at a lactate value of four $mmol.L^{-1}$ (Sjodin and Jacobs, 1981; Foss and Keteyian, 1998). It has been reported that OBLA corresponds to the highest steady-state work intensity that can be maintained for a prolonged time, and is therefore an excellent predictor of endurance performance (Sjodin and Jacobs, 1981; Stegmann and Kindermann, 1982; Sjodin and Svedenhag, 1985). OBLA is therefore also an estimate of a cyclist’s exercise economy.

5. Percentage type I muscle fibers in the *Vastus Lateralis*

There are 10 major leg muscles used during the entire cycling action. It includes the *Vastus Lateralis*, *Rectus Femoris*, *Vastus Medialis*, *Biceps Femoris*, *Semitendinosus*, *Semimembranosus*, *Tibialis Anterior*, *Soleus*, *Gastrocnemius*, and the *Gluteus Maximus* (Gregor and Conconi, 2000).

Muscle fibers can be divided into type I and type II muscle fibers, where type I is called the slow-twitch fibers because of their relatively slow contraction and relaxation times, their high content of myoglobin and enzymes that favor aerobic energy production. This means that type I fibers can produce energy for a long time if a

sufficient amount of oxygen is available. Type II fibers contain a lower aerobic capacity, but a high anaerobic capacity (it can produce energy without the use of oxygen), and are called fast-twitch fibers (used during sprinting). Type II fibers can be divided into type IIa and type IIx fibers. Type IIa is generally described as being more aerobic than type IIx fibers. With the correct training (i.e. endurance training), type IIx fibers can take on the characteristics of type IIa fibers (Burke, 1995; Janssen, 2001).

Coyle *et al.* (1988) found that a high percentage type I muscle fibers, associated with years of cycling experience, determine the factors associated with VO_2 at lactate threshold. In a follow-up study, Coyle *et al.* (1991) found that “elite-national class” cyclists can be separated from “good-state” cyclists by the percentage type I muscle fibers in the *Vastus Lateralis* ($66.7 \pm 5.2\%$ versus $46.9 \pm 3.8\%$).

6. Body composition

The average height of competitive mountain bikers is between 176 and 180 centimeters (Impellizzeri and Marcora, 2007). Padilla *et al.* (1999; 2000) found that height in road cyclists can range between 160 and 190 centimeters with an average height of 180 centimeters. Recent research has shown that elite and high-level mountain bikers have an average body mass between 65 and 69 kilograms (Lee *et al.*, 2002; Impellizzeri *et al.*, 2005a). Average body mass in road cyclists is 68.8 kilograms, ranging between 53 and 80-kilograms (Padilla *et al.*, 1999 and 2000), with an average percent body fat of 8%, ranging between 6.5 and 11.3% (Lucia *et al.*, 1999; Fernandez-Garcia *et al.*, 2000).

Body composition can also be described as the relationship between body mass and body fat, and the effect that body mass can have on cycling. Like in most other sports, carrying excess fat during cycling is a disadvantage. It is not just the cyclist's mass that determines the amount of muscle mass needed for power, but it is also essential to measure the amount of unnecessary fat. A person's body mass can be influenced by the size of his or her body structure, gender and genetics (Burke *et al.*,

1995). Normally body fat in male cyclists ranges between 8-12%, and in woman cyclists between 11-15% (Neumann *et al.*, 1992). High-level off-road cyclists have shown to have an average body fat percentage lower than 6.4% (Lee *et al.*, 2002; Impellizzeri *et al.*, 2005a), while elite mountain bikers range between 8.5 and 14.3% (MacRae *et al.*, 2000; Warner *et al.*, 2002; Wingo *et al.*, 2004).

Coyle *et al.* (1991) stated that body size is very important in time trial performance, and also found that lean body weight can be related to power output during a one-hour time trial. Body mass also plays a very important role during uphill cycling, determining gravity-dependent resistance (Swain *et al.*, 1987).

Impellizzeri *et al.* (2005a; 2005b) illustrated in their studies the importance of taking body mass into account when investigating the physiological determinants of off road cycling. They determined that both power output and VO_2 at the respiratory compensation threshold (similar to the ventilatory threshold) were significantly associated with cross-country race performance only when normalised to body mass. Similarly, the best correlation ($r > 0.90$) between off-road racing and VO_{2max} , PPO and LT were found when these variables were normalised to body mass. These findings are in agreement with the conclusions of Lee *et al.* (2002) that power to weight characteristics are important for success in off-road events.

C. Mountain biking

In the last decade mountain biking has become a popular recreational and competitive activity (Impellizzeri and Marcora, 2007). Cross-country racing, the most popular off-road event, has only been recognised by the International Cycling Union in 1990, with the first World Cup series in 1991, and for the first time contested in the Olympic Games in 1996 in Atlanta (Prins *et al.*, 2007). It is therefore not surprising that there are only a few studies published thus far on the physiological aspects of this sport.

1. Characteristics of mountain biking

Mountain biking can be divided into cross-country racing (mass-start endurance competition), downhill and stage races (Impellizzeri *et al.*, 2002). Cross-country circuit racing involves the completion of several laps (between six and nine kilometers long) on an off-road circuit, and usually lasts between 120 and 135 minutes for men. The courses usually include several steep climbs and descents, and stretch over a terrain of forest roads and tracks, fields and gravel paths.

The exercise intensity during cross-country races lasting at least two hours is very high, with average heart rates close to 90% of maximum heart rate (i.e. 84% of maximum oxygen uptake). Power output values may reach 250 to 500 watts during uphill cycling (Stapelfeldt *et al.*, 2004). Races are further characterised by a very fast paced start (in order to obtain a good position), large rolling resistances, a number of climbs (cycling against gravity), and the isometric contractions of the arm and leg muscles for bike handling and stabilisation. This results in the cyclist exercising more than 80% of the race above his/her lactate threshold. The ability to maintain high work rates over extended periods is essential to perform at a high level in mountain biking. Aerobic fitness, cycling economy, anaerobic power and capacity, and technical ability are significant parameters associated with cross-country performance (Impellizzeri and Marcora, 2007). It has also been suggested that body mass may be more important in mountain biking than in many road cycling events.

Baron (2001) studied the anaerobic and aerobic characteristics of off-road cyclists by comparing 25 national- and international off-road cyclists with 60 sport science students (who did not perform specific cycle exercises more than twice a week). Maximal aerobic power (VO_{2max}) and power output at a fixed lactate value (OBLA = 4 mmol.L⁻¹) were measured by performing an incremental maximal aerobic test on a cycle ergometer. Anaerobic power was determined on a cycle ergometer by performing a 10-second anaerobic power test at a cadence ranging between 50 and 140 (increasing every 10 seconds), measuring both the average power output and the

peak power output. The mountain bikers showed a higher VO_{2max} , peak power output, and power output at OBLA, compared to the students during the aerobic capacity test. Both mean and peak power output were significantly higher compared to the students, indicating the superior anaerobic power of the mountain bikers. Coyle *et al.* (1991) also studied the physiological responses of “elite-national class” and “good-state class” cyclists, and found that “elite-state cyclists” have the ability to generate a higher peak power during the downstroke of the pedaling movement. These results may be explained by the physiological and biomechanical adaptations in skeletal muscle, specifically type I muscle, following years of endurance training.

Unlike road races, the initial stages of cross-country races are very important for overall performance (Impellizzeri and Marcora, 2007). Both Impellizzeri *et al.* (2002) and Stapelfeldt *et al.* (2004) measured heart rates close to maximum just after the start of the race, mainly because cyclists try to get into the front positions of the race, to avoid getting stuck behind other cyclists when the road starts to narrow into a single track. Thereafter, cyclists settle down and exercise intensity drops slightly. This was elegantly demonstrated in a study by Wingo *et al.* (2004). They measured blood lactate concentrations during a multi-lap off-road race. After the first lap, blood lactate values ranged between 8.1 and 9.1 mmol.L⁻¹, while the values dropped to 5.7 and 6 mmol.L⁻¹ after the last lap.

2. A comparison of mountain biking and road cycling

The exercise intensity in cross-country cycling is similar compared to short road cycling events, like time trials (Padilla *et al.*, 2000), but higher compared to long duration road cycling (Padilla *et al.*, 2001).

A reasonable explanation for this difference is the long duration (four to six hours) of road events compared to an off-road event that typically lasts not more than two hours. The tactics involved in the events are also vastly different (Lucia *et al.*, 2001; Mujika and Padilla, 2001; Impellizzeri *et al.*, 2002). The rolling resistance and the

tough terrain that the off-road cyclists have to deal with are much worse than on-road cycling (Padilla *et al.*, 1999). During road cycling it is also much easier to draft behind other cyclists (McCole *et al.*, 1990) than in mountain biking, and together with greater rolling resistance it makes it much harder to cycle on off-road terrains. During mountain biking the arms and legs of the cyclist contract isometrically, it absorbs shock and it plays an important role in stabilising the body and the bike (Impellizzeri *et al.*, 2002). According to Cable (1990), isometric muscle contractions lead to higher heart rate responses during submaximal cycling. All these factors thus explain the difference in exercise intensity during cross-country cycling compared to road cycling.

Lee *et al.* (2002) compared the physiological characteristics of internationally successful mountain bikers ($n = 7$) and professional road cyclists ($n = 7$). Anthropometrical measurements, an incremental cycle ergometer test, and a 30-minute laboratory time trial were completed by seven mountain bikers and seven road cyclists (Table 3.1).

Table 3.1: The maximal exercise capacity of the mountain bikers and the road cyclists (Lee *et al.*, 2002).

| | Mountain Bikers | Road Cyclists |
|--|------------------------|----------------------|
| PPO (W) | 413 ± 36 | 431 ± 12 |
| PPO/Weight (W.kg ⁻¹) | 6.3 ± 0.5 * | 5.8 ± 0.3 |
| VO _{2max} (L.min ⁻¹) | 5.1 ± 0.5 | 5.4 ± 0.1 |
| VO _{2max} (mL.kg ⁻¹ .min ⁻¹) | 78.3 ± 4.4 * | 73 ± 3.4 |
| VE (mL.min ⁻¹) | 139 ± 24 | 149 ± 12.9 |
| Peak blood lactate (mmol.L ⁻¹) | 10.1 ± 2.6 | 10.6 ± 1.4 |
| Cycling economy (W) | 91 ± 6 | 86 ± 4 |
| HRmax (bpm) | 189 ± 5 | 191 ± 9 |

$p < 0.05$

PPO = peak power output

VE = minute ventilation

HR = heart rate

Table 3.2: The time trial performance of the mountain bikers and the road cyclists (Lee *et al.*, 2002).

| | Mountain Bikers | Road Cyclists |
|---|------------------------|----------------------|
| Average PO (W) | 358 ± 34 | 370 ± 11 |
| Average PO/Weight (W.kg ⁻¹) | 5.5 ± 0.5 * | 4.9 ± 0.3 |
| Average lactate (mmol.L ⁻¹) | 6.4 ± 2.2 | 6.1 ± 1.5 |

p < 0.05

PO = power output

Lee *et al.* (2002) found that there were no differences in height and age, but a significant difference in weight, with the mountain bikers being much lighter and leaner. The latter finding makes sense, because mountain bikers do a significant amount of climbing. While body mass is less important during road cycling, particularly in flat road stages. The mountain bikers' relative peak power output and VO_{2max} values were higher than the road cyclists' values, mainly as a result of their lower body mass. The time trial results showed that the mountain bikers had a higher average power output relative to their body weight, but there were no further significant differences in results. As a result of their lower body mass, the mountain bikers also had a significantly higher average power to weight ratio during the 30-minute time trial. Otherwise, their performances were similar to that of the road cyclists.

The findings of Lee *et al.* (2002) is an affirmation of previous research that a cyclists' maximal power to weight ratio can be used to predict mountain climbing ability (Nevill *et al.*, 1992; Padilla *et al.*, 1999). This is also in agreement with Padilla *et al.* (1999) and Lucia *et al.* (2000a) who found that uphill road specialists weigh less, and have a higher maximum oxygen uptake relative to body mass compared to other road cyclists.

In another study done by Impellezzeri and Marcora (2007), the physical characteristics of 15 off-road cyclists were compared to 34 on-road cyclists. The latter

group consisted of nine climbers, 15 all-terrain riders and 10 flat road specialists. The off-road cyclists, climbers and all-terrain road-cyclists had similar relative and absolute VO_{2max} -values, body mass and peak power output, and these results were significantly different from the flat road specialists. As before (Lee *et al.*, 2002), these authors confirmed that off-road cyclists have similar physical characteristics than all-terrain on-road cyclists and climbers.

The higher exercise intensity and shorter duration of off-road cycling, suggest that mountain bikers should follow a different training strategy than road cyclists. Thus, high intensity, short duration exercise sessions, for instance interval training, must form a significant part of a mountain bikers training program.

Warner *et al.* (2002) studied the differences in bone mineral density between elite mountain bikers ($n = 16$), road cyclists ($n = 14$) and recreationally active men ($n = 15$). The bone mineral density of the femur neck, lumbar spine, greater trochanter and Ward's triangle was measured with dual-energy X-ray absorptiometry, while leg strength was measured with a leg-press machine and VO_{2max} was measured during a maximal aerobic ergometer test. When bone mineral density was adjusted to age and body mass, the mountain bikers had a significantly higher bone mineral density compared to the road cyclists and recreationally active men. There were no significant differences in leg strength and VO_{2max} between the two cycling groups. In general, a road cyclist does not take the same amount of impact on the flat road compared to a mountain biker on rough terrain. Furthermore, mountain cycling requires cycling at different speeds, gradients and intensities, which may lead to a greater osteogenic stimulus through the greater loading forces. The arms also take a lot of shock absorption, which is less during road cycling. These additional demands might have an effect on the loading patterns of the bone and therefore influence the structure of the cyclist's skeleton, thus explaining the findings of Warner *et al.* (2002).

Although mountain biking and road cycling have many similar physiological requirements and characteristics, there are also important differences. Prins *et al.*

(2007) noted that certain physiological characteristics may differ between road cycling and mountain biking, because of different riding techniques, terrain conditions and strategies involved with each sport. Therefore it can be speculated that different laboratory tests should be performed on road cyclists and mountain bikers.

Prins *et al.* (2007) compared traditional laboratory tests (i.e. VO_{2max} and time trial) with variable fixed intensity protocols and related these responses with actual performances in the field. The latter included an outdoor competition (four or six laps on an eight-kilometer route) and an outdoor time trial (four laps on an eight-kilometer route), performed on the same course.

Results showed that the commonly used incremental test to fatigue can be used to measure mountain biking performance. The variable fixed intensity tests, in which an attempt was made to simulate the mountainous terrain of a mountain bike race, did not predict actual field performance any better. The important finding was that the outdoor time trials correlated better with peak power output relative to body mass, than with absolute peak power output. This not only confirms the importance of body mass in mountain biking, but also places mountain biking in the same category as uphill cycling.

D. A comparison of track cycling and road cycling

Road cycling usually last between four and six hours, while track cycling mostly lasts between 62 and 300 seconds (1000 to 4000 meters). The short-term endurance for a track cyclist normally lasts for one to two minutes, while medium-term endurance exercise lasts between two and 10 minutes (Neumann *et al.*, 1992). Track cycling does include a long duration event, which lasts for one hour (Craig and Norton, 2001). During 1000- and 4000-meter track cycling a cyclist sprints for three minutes at a low effort, and 20 seconds at a maximum effort. This requires a high activation of the central nervous system, and it involves a high recruitment of fast-twitch muscle fibers. Track sprinters usually have a high proportion (35 to 65%) of fast-twitch fibers.

Through strength training cyclists increase the size (hypertrophy) of these fast-twitch fibers (Neumann *et al.*, 1992). Type II fibers (fast twitch fibers) are therefore the major muscle fibers when developing a higher power output, and a high peak power output leads to an improved sprint performance during cycling (Stone *et al.*, 2004).

In most sports, a low body fat is necessary for the best performance, but with track cycling it is even more important. According to Gregor (2000), unnecessary body fat can have a triple effect in decreasing performance, because it increases the energy cost during acceleration, the rolling resistance, and the projected frontal surface of the cyclists' body during sprinting. Therefore, in both track cycling and mountain biking, body mass and percentage body fat are important determinants of performance.

During short events, energy is mainly supplied through anaerobic glycolysis. In longer competitions (one to five minutes), 50% of the energy is supplied under anaerobic conditions. If exercise continues for longer, aerobic metabolism starts to dominate. Lactate concentrations during these short sprints can build up to 18 and 22 mmol.L⁻¹. This intensive training by track cyclists leads to a much higher anaerobic power capability than road cyclists, mainly because of a higher glycolytic enzyme activity level. Track cycling further requires much higher central nervous system activation, and therefore higher levels of catecholamine release occur (Neumann *et al.*, 1992).

For road cyclists, where long-term endurance are much more important, the potential power of the muscles are particularly dependant on the fatigue-resistant slow-twitch fibers. During prolonged exercise, there is a greater recruitment of slow-twitch fibers, which usually makes up between 70 and 95% of the road cyclist's muscle fibers (Neumann *et al.*, 1992).

According to Craig and Norton (2001) a track cyclist's power output depends on bicycle speed and design, the cyclists' body size and position, and environmental factors. Stone *et al.* (2004) argued that maximum strength, power output and peak-rate-of-force developments (PRFD) are the main variables for power and strength in

sports, including cycling. Top-quality sprinters are stronger and more powerful than cyclists who do not specialize in sprinting.

E. Conclusion

Professional cyclists all require high aerobic capacities, as cycling is mainly an endurance event. Both aerobic and anaerobic power are important, during road cycling and mountain biking, however because of the higher physical demands of mountain biking, anaerobic power and an optimal power to weight ratio are even more critical. To perform at an elite level, and gain optimal results, it is important to take into account the physiological requirements of the specific cycling event, and to develop performance tests and training programs as specific as possible to each type of sport.

CHAPTER FOUR

INTERVENTION TRAINING FOR CYCLISTS

A. Introduction

To improve overall fitness and cycling performance, it is important to develop a stronger body, and to utilize all the available equipment and training techniques possible (Burke, 1995). A competitive road cyclist has a very large training volume, normally ranging between 27000 and 39000 kilometers per year (Jeukendrup *et al.*, 2000). However, when preparing a cycling program, it is important to develop a program with the most effective combination of training intensity, frequency and duration (Zappe and Bauer, 1989; Hawley and Burke, 1998).

Because power output and endurance are so important to cyclists, a cyclist's aerobic capacity must be well developed. Therefore it is important to train the energy-producing mechanism required for muscular contractions. Aerobic endurance plays a big role during all types of racing, but especially during stage racing, while aerobic power is important during breakaways, climbing, and time trials. Anaerobic capacity plays an important role during the shorter phases of cycling, such as sprints (which includes finishing sprints, sprints around corners), short-climbs done at full speed, and while closing a gap.

Generally, a training program is a mixture of different types of training to improve the power and endurance of the cyclist (Gregor and Conconi, 2000). A successful training program will lead to an improvement in the body's ability to take up, distribute and utilize oxygen (VO_{2max}), an improvement in exercise economy and a higher anaerobic/lactate threshold (Brandon, 1995).

Power output refers to the amount of power a cyclist can generate while cycling, and is a major predictor of cycling potential (Faria *et al.*, 2005). It plays an important role

with other submaximal physiological variables, in determining exercise prescription and performance velocity during time trials (McNaughton *et al.*, 2006).

B. Training the aerobic and anaerobic energy systems

For every cyclist it is important to set up a yearly training plan, including time frames with specific types of training. This also allows a cyclist to set up short-and long-term goals, reaching the best possible training and competition results (Burke, 1995). Burke (1995) divided a yearly plan into four periods, namely a general preparation phase (11 weeks), a specialization phase (13 weeks), a competition period (22 weeks) where the cyclist will peak, followed by a transition period (six weeks). During the general preparation and the specialization phase the cyclist will progressively increase his/her amount of kilometers. During the general preparation the cyclist includes general conditioning (like weight training) and performs cross-training. During this period the cyclist also trains to improve his/her aerobic energy system, especially aerobic endurance. During the specialization phase the resistance program will enter the power phase, and cycling intensity will increase more of the aerobic power energy system. Towards the end of this phase the cyclist also starts to work on the anaerobic energy system (Burke, 1995).

During the competition phase, the cyclist wants to perform at his/her best. Therefore the anaerobic power and endurance energy systems should be optimally trained and maintained. During the competition phase, mental and tactical factors also play a very important role. After the competition phase the cyclist goes into a transition period (active rest), recovering emotionally and physically, before once again, starting with a new season (Burke, 1995; Bompa, 1999).

Cycling uses two metabolic pathways for producing energy, with oxygen (aerobically) during long distance rides, and without oxygen (anaerobically) during short bouts of exercise. Long distance cycling greatly depends on energy from fats and carbohydrates (Burke, 1986).

1. Training the aerobic energy system

It is easy to develop ATP production, but it also declines easily with a prolonged suspension of training (Gregor and Conconi, 2000). The purpose of endurance training is to improve muscle glycogen storage (Greiwe *et al.*, 1999), and increase mitochondrial enzymes, while there is no real change in glycolytic enzymes (Holloszy, 1975; Hamel *et al.*, 1986).

According to Bassett and Howley (2000) the increase of VO_{2max} results primarily from the increase in maximal cardiac output. When a muscle is overperfused during exercise, its capacity for consuming oxygen increases, therefore the O_2 delivery (carrying capacity) and not O_2 extraction can be seen as the primary limiting factor for VO_{2max} during exercise. Other limiting factors for VO_{2max} are the skeletal muscles' characteristics and pulmonary diffusing capacity (Bassett and Howley, 2000).

Training for aerobic power

Maximal aerobic power is the maximal rate at which energy can be produced for the functioning of a muscle, through oxidative metabolism (Thoden, 1991). Aerobic power is normally used during breakaways, climbing and time trials (Gregor and Conconi, 2000). A good aerobic base (endurance) is needed before performing this type of training. Normally, to improve aerobic power requires training at VO_{2max} (Gregor and Conconi, 2000), or for trained cyclists, even at an intensity of 80 to 90% of their maximal heart rate (Burke, 1995). Cunningham *et al.* (1979) found an increase in maximal aerobic power after training at both 80 and 100% of VO_{2max} . When a cyclist train to improve aerobic power it stimulates the development of oxygen transport (cardiocirculatory system) and aerobic fuel breakdown. Aerobic training therefore enhances both the central and neuromuscular components of aerobic metabolism (Gregor and Conconi, 2000).

Usually, a training session starts with a 30-minute warm-up, during which all the mechanisms of energy expenditure are progressively activated. The session starts at a low intensity, and slowly progresses to a submaximal intensity. In cycling, one would gradually increase the cadence, while staying in the same moderate gear. The gradual increase in intensity during the warm-up prevents the lactic acid from building up, but at the same time activates the cardiocirculatory and the muscular systems. The anaerobic energy systems can also be activated during the warm-up period, by adding short and rapid accelerations (Gregor and Conconi, 2000).

To improve aerobic power, training must take place at an intensity that will stimulate the maximal activation of the aerobic metabolism (i.e. training at VO_{2max}) for a long enough period. However, the activation of anaerobic glycolysis and subsequent lactate accumulation that occurs at this high intensity, makes this type of training very difficult. Therefore, training should be done at an intensity below the lactate threshold (determine heart rate at the lactate threshold, and train accordingly). The cyclist would also be able to train for a longer time at this lower intensity, compared to training at VO_{2max} . When the cyclist gets use to training at this intensity, the number of sessions and the length of the workout can be increased. This type of training can be repeated every three days, which allows for enough recovery time between sessions (Gregor & Conconi, 2000).

Training to improve aerobic power brings about a series of structural and functional changes in the reception and transport of oxygen (O_2) from the lungs to the muscles (changing the respiratory exchange, cardiac function and the mitochondrial enzymes) and to the release and muscular utilization of O_2 (myoglobin, mitochondria and mitochondrial enzymes). There is a slight increase in VO_{2max} , anaerobic threshold, and exercise intensity compared to VO_2 and heart rate. With this there is a reduction in resting heart rate, maximum heart rate, and the heart rate at anaerobic threshold. All these changes assist in increasing the cyclist's overall performance and race pace (Gregor and Conconi, 2000).

Training for aerobic endurance

Training for aerobic endurance has a lower intensity than aerobic power, and plays an important role during stage racing (Gregor and Conconi, 2000). It is also sometimes referred to as base training. Glycogen stores, in the muscles and liver, are only sufficient for intensive efforts lasting up to 90 minutes. Aerobic endurance is closely related to the power needed to perform intense muscular work while maintaining as much glycogen reserves as possible. This type of training must also improve the utilization of fatty acids during exercise which will spare the glycogen stores. A greater reliance on fat metabolism correlates with greater endurance capacity (Gregor and Conconi, 2000). Endurance training can increase the body's potential to store carbohydrates within the muscles and liver, and to burn more fat (Burke, 1995).

During aerobic training, heart rate normally ranges between 65 and 85% of maximum heart rate (Human *et al.*, 1990). Cycling done at 15-20% below the anaerobic threshold has been shown to be efficient in improving aerobic endurance. Since this type of training is not too tough, it can be performed every second day. Aerobic endurance can be done on flat roads or long climbs, and can continue for up to seven hours (Gregor and Conconi, 2000). Engaging in endurance training in the early season, also improves ligament and tendon strength, which prepares the body for the harder interval training sessions (Burke, 1995).

As the relative use of fatty acids increases with a consequent sparing of glycogen, the relationship between exercise intensity and heart rate stabilizes, and there is a progressive reduction in heart rate curves with prolonged submaximal exercise (Gregor and Conconi, 2000).

2. Training the anaerobic energy system

This type of training mostly takes place after the cyclist has done a fair amount of aerobic base training for an extended period of time (six to eight weeks). Training to

improve the anaerobic energy system normally takes place closer to or during the competition phase (Bompa, 1999). Both anaerobic power, and anaerobic endurance, requires training at an intensity of 95 to 100% of maximum heart rate.

Training for anaerobic power

Anaerobic power is needed to sprint at a maximum speed during the end of a race. The percentage of fast twitch fibers in a cyclist's muscles and its optimal recruitment plays a major role in determining an athlete's anaerobic power output. The metabolic characteristics of the muscles are also determined by the muscle fiber type. It is much easier to improve a cyclist's aerobic power, than to increase anaerobic power, which responds more difficult to training. During normal racing, cyclists frequently employ a lot of power bursts, and thereby develop their anaerobic mechanisms (Gregor and Conconi, 2000). During sprint training, lasting 10 to 25-seconds, ATP and CP are the two fuels responsible for muscle functioning (Human *et al.*, 1990).

There are other types of interval training that develops anaerobic power. The first of these is to improve anaerobic alactacid power. This can be done by sprinting maximally for seven to eight seconds repeatedly for up to 10 times, allowing a recovery of two minutes between sprints. Exercise starts at a low intensity and can be done on flats or climbs. This series can be repeated three times in a single training session. It results in modest lactate accumulation and thus can be performed every day.

The second type of interval training improves the anaerobic lactacid power. This is done by maximal speed variations, repeated three to five times, allowing a five minute recovery between repetitions. This series can be repeated two to three times, with 20 minutes rest in between at a very low intensity (this allows for lactate clearance). This exercise starts at an intensity that is close to the anaerobic threshold, which minimizes lactate accumulation during each speed variation (cyclist varies the speed of each interval). This type of training can also be done on flats or climbs, but

because of a high build-up of lactate concentration it cannot be repeated more than three times a week. This type of training (to improve anaerobic power) is usually done from 30 to 40 days before the start of the racing season (Gregor and Conconi, 2000).

Sprint training has more of an effect on the glycolytic capacity, and less of an effect on the mitochondrial content of the muscle (Kubukeli *et al.*, 2002). Training for aerobic power easily causes muscular changes. It increases the concentrations of enzymes for glycolysis and phosphocreatine kinase, and also increases the speed of anaerobic glucose breakdown and related anaerobic synthesis of adenosine triphosphate (ATP). There are also functional changes in the motor nerves of the muscular groups involved with the training and the endocrine system (Gregor and Conconi, 2000). MacDougal *et al.* (1998) found that short but intense sprint training can enhance glycolytic and oxidative enzyme activity, as well as maximum short-term power output.

Training for anaerobic endurance

A cyclist that has a good anaerobic endurance has a big advantage when it comes to the stage in the race when a maximal effort (sprinting) is required for several minutes. To improve anaerobic endurance, it requires the same type of training as done for anaerobic power, but continues for a longer duration with shorter rest periods (Gregor and Conconi, 2000). During these longer sprints, the anaerobic breakdown of glycogen plays a more important role, and this is where lactic acid is produced and starts to accumulate with continued exercise (Human *et al.*, 1990). By accumulating great quantities of lactate, it stimulates the anaerobic breakdown of glucose and the capacity to withstand high lactate concentrations (Gregor and Conconi, 2000).

The ability to withstand great quantities of accumulated lactate may depend on improved efficiency of the buffering system in the muscles. Improvements may also depend on acceleration in lactate diffusion in the blood and in the extracellular spaces, lactate removal of the blood by the liver and heart, and whether muscles

reuse lactate directly after exercise (Gregor and Conconi, 2000). This type of training is useful during the last kilometer of a race when an intense effort is needed (Human *et al.*, 1990).

3. Conclusion

Laursen and Jenkins (2002) stated that although a large amount of research has been done to describe sedentary and recreationally individuals' physiological adaptations to endurance training, not a lot of studies have examined the physiological and performance responses of highly trained athletes to an adapted training program. Well-trained athletes have a higher aerobic capacity, lactate threshold and economy efficiency (Jones and Carter, 2000; Laursen and Rhodes, 2001).

To achieve success in competitive cycling, cyclists are required to cycle thousands of kilometers per year. When an increase in training volume no longer improves fitness, or cycling performance, cyclists include interval training into their program. For improved cycling performance, cyclists need to train sufficiently to improve their physiological characteristics (Faria *et al.*, 2005). Combining resistance training and different modes of interval training, can lead to improved cycling performance, especially at the elite level where any improvement in physiological characteristics can contribute to improved cycling performance.

C. The effect of endurance and interval training on cycling performance

As mentioned previously, endurance training is normally done during the preparation phase of a cyclists' annual plan, improving the cyclists' aerobic energy system, preparing the cyclists for the interval training which normally follows after base training. Endurance performance and aerobic fitness can be increased by improving the body's ability to take up, distribute, and then use oxygen (VO_{2max}), or by improving the gas-exchange threshold (GET) or exercise economy (Brandon, 1995). Endurance

training thus improves peak oxygen uptake, increases capillary density in the working muscles, raises blood volume, and also decreases heart rate at a certain exercise intensity (Kubukeli *et al.*, 2002).

1. Submaximal endurance training

To determine the effect of endurance training on the oxygen uptake of trained cyclists, Norris and Petersen (1998) studied the responses of 16 competitive cyclists (14 men and two women) to an eight-week endurance cycle program, during the beginning of their preparatory period. Ventilatory threshold and VO_{2max} was determined during a maximal aerobic test on a cycle ergometer. VO_2 was also measured during two specific power outputs (PO1 and PO2) during the test (78 and 157 watts for men, and 55 and 110 watts for woman). Both PO1 and PO2 were well below the ventilatory threshold. Time was also measured during a 40-kilometer time trial. These tests were performed before, after four and eight weeks, while the cyclists followed a progressively overloading endurance program training five days a week. The training program consisted of cycling at a heart rate corresponding to the ventilatory threshold (\pm two beats per minute) for the first four sessions in a week, while the last session was at a lower intensity (15 beats.min⁻¹ below the ventilatory threshold).

From pre- to post-training, time constants for oxygen uptake transitions at both PO1 and PO2 were much faster, while results also showed a statistically significant improvement in VO_{2max} (seven percent), and VO_2 (23%) and power output (27%) at ventilatory threshold. The cyclists' 40-kilometer time trial performance also improved significantly (8.4%). The increase in ventilatory threshold can be linked to the increase in VO_{2max} . These results show that oxygen uptake can be improved with endurance training in already well-trained cyclists.

Laursen and Jenkins (2002) stated that submaximal training in recreationally and sedentary active individuals, resulted in physiological adaptations and an improved

endurance performance, but it remains unclear what impact this type of training will have on already highly trained endurance athletes. Londeree (1997) found that when a trained individual reaches a VO_{2max} value of over $60 \text{ ml/kg/min}^{-1}$, submaximal training would not further increase endurance performance. Athletes reach a plateau in metabolic adaptations that result from submaximal training (Laursen and Jenkins, 2002), after which VO_{2max} and the anaerobic threshold do not increase any further (Costill *et al.*, 1988; Lake and Cavanagh, 1996; Londeree, 1997).

Londeree (1997) studied the effect of continues training on the training status of athletes (trained versus untrained), training at an intensity equivalent to ventilatory threshold. The untrained individuals showed a clear improvement in performance and associated physiological variables, while there were no further improvements for the trained individuals. Costill *et al.* (1988) doubled swim-training distance in trained athletes over a 10-day period (from 4266 to 8979 meters per day), maintaining the same training intensity. Results showed no further improvements in swimming performance or aerobic capacity.

These findings show that submaximal training can improve performance (VO_{2max}), although a cyclist might reach a plateau at some stage. At this point the athlete will probably respond better to high intensity training (Laursen and Jenkins, 2002).

2. High-intensity interval training

High-intensity training is normally achieved with the use of interval training. It is characterised by repeated bouts of short to moderate duration (five seconds to five minutes) completed at an intensity higher than the anaerobic threshold. Exercise bouts are separated with low-intensity cycling, usually named recovery sessions (Laursen and Jenkins, 2002). This type of training is normally performed in the weeks leading into the cyclists' competition period, and is also continued throughout this phase (Burke, 1995). According to Londeree (1997), trained cyclists should have, by this time, VO_{2max} -values greater than $60 \text{ mL.kg}^{-1}.\text{min}^{-1}$.

Paton and Hopkins (2004) stated that high-intensity training has a better effect when performed during the non-competitive phase of the season, than when performed during the competitive phase when athletes normally include high-intensity training into their programs. Paton and Hopkins (2004) found improvements of up to eight percent in endurance power output. In a follow-up study, Paton and Hopkins (2005) found improvements between six and nine percent in endurance performance, and during this study, the high-intensity resistance training (explosive) was performed during the competitive phase of the season. The high-intensity work bouts might affected peripheral adaptations in the working muscles by increasing the muscle's buffering capacity and causing a greater resistance to fatigue of the locomotor muscles (Nevill *et al.*, 1989).

Although coaches and endurance athletes have long acknowledged the value of high intensity interval training to enhance endurance performance, it is not known what type of interval training results in the best improvements. Laursen *et al.* (2002) studied the effect of three different high intensity interval training programs on the endurance performance of 38 well-trained cyclists and triathletes. The subjects were divided into three interval training groups and one control group. The interval training groups trained twice a week for four weeks. The control group ($n = 11$) continued with their low-intensity base-training program.

Subjects in group one ($n = 8$) performed eight intervals at VO_{2max} in a session, with a 1:2 recovery ratio. Group two ($n = 9$) performed the same intervals as group one, except that their recovery time was longer (until the heart rate was 65% of HR_{max}). Group three ($n = 10$) performed twelve 30-seconds bouts at 175% of peak power output, with four and a half minutes recovery.

The total amount of work completed (W_{train}) with each high intensity training session was calculated using the amount of time completed at the specific workload. All three training groups improved their W_{train} , with group one performing significantly more

work than group two, and group two performing significantly more work than group three.

Peak VO_2 also increased significantly in group one, two and three, with a significant improvement in group one and two compared to the control group. The peak VO_2 also increased significantly in group two compared to group three. All three interval training groups' time trial performance and peak power output increased significantly, and were significantly better than the control group. Group two showed a significantly greater improvement in time trial peak power output compared to group three.

Laursen *et al.* (2002) concluded that group two showed the most improvement in time trial performance, peak power output, and peak VO_2 . This was the only group where heart rate was used to determine recovery, while the other two groups' recovery was time-based. It can be speculated that the improvement in group two after interval training was due to the effective recovery in between the interval bouts. Furthermore, the study shows that high intensity training is effective to improve 40-kilometer time trial performance, peak power output and peak VO_2 in already highly trained cyclists.

Tabata *et al.* (1997) found that a high-intensity intermittent training (similar to interval training) program can even result in larger VO_{2max} gains than training at submaximal intensity for five hours a week over a six-week period. Six weeks of submaximal aerobic training (at 70% of VO_{2max}) in moderately trained men, showed no improvement in anaerobic capacity, but a nine percent increase in VO_{2max} (from $53 \pm 5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ to $58 \pm 3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). On the other hand, six weeks of high-intensity intermittent exhaustive exercise improved anaerobic capacity by 28%, and VO_{2max} by 14.6%.

Stepito *et al.* (1999) also studied the effect of interval training programs on the time-trial performance of endurance cyclists. 20 male provincial-level cyclists performed a 40-kilometer time trial (measuring time), a maximal aerobic power test, and a sprint test on a cycle ergometer. After the testing the cyclists were randomly divided into five

interval-training groups, after which the subjects performed six sessions over a three-week period. Group one performed twelve 30-second bouts at 175% of peak power (four and a half minutes recovery); group two performed twelve 60-second bouts at 100% of peak power (four minutes recovery); group three performed 12 two-minute bouts at 90% of peak power (three minutes recovery); group four performed eight four-minute bouts at 85% of peak power (90-seconds recovery); and group five performed four eight-minute bouts at 80% of peak power (60-seconds recovery).

Results showed a strong relationship between training intensity and time trial performance, with maximal improvements at 85% of peak power output with exercise bouts of three to six minutes in duration. It is interesting to note that a 40-kilometer time trial is normally performed at an average intensity of 80% of peak power. This compares favourably to the findings in this study, namely that performance was best improved at a training intensity equal to 85% of peak power.

The four-minute and 30-second training bouts resulted in statistically significant improvements in 40-kilometer time-trial performance ($p < 0.01$), while the one and eight-minute working bouts showed little or no improvement. These are interesting findings, as it is known that 30-second work bouts are normally performed with oxygen-independent glycolysis, while a 40-kilometer would depend on power provided by the aerobic system (Hawley and Hopkins, 1995). Therefore the reason for improvement in time trial performance after 30-second sprint training is unclear.

Stepito *et al.* (1999) also found a strong correlation ($r = 0.92$) between changes in percentage of peak power after the interval training sessions and the changes in 40-kilometer time trial performance. The four-minute working bouts showed the maximum improvement in performance (peak power). This supports previous research done by Lindsay *et al.* (1996) and Westgarth-Taylor *et al.* (1997), who also found an increase in peak power after using five-minute working bouts at 80 to 85% of peak power. The sprint test on the cycle ergometer did not show any significant differences, but Stepito *et al.* (1999) stated that the sprint test proved to be relatively

unreliable (i.e. not reproducible), and therefore it was unlikely to detect any significant changes.

When performing interval training at a high cadence, it has been shown to improve endurance performance, but according to Taylor-Mason (2005), this type of training can be more effective if one trains at high resistance and low cadence.

Taylor-Mason (2005) studied the effect of high-resistance interval training in 12 trained cyclists during their competitive season. The cyclists replaced a part of their normal training program with race-specific high resistance-high cadence interval training for eight weeks, training twice a week in a laboratory, while the control group ($n = 10$) continued with their normal training. Maximal aerobic capacity and a 40-kilometer time trial (time and mean power) were measured on a Kingcycle ergometer before and after eight weeks of training. The experimental group cycled in their highest gear on their bike, and graded resistance on the simulators produced and maintained the highest power output possible for the cadence. The session included five to six intervals of three to 22 minutes per session, while the total duration of the session increased progressively from 25 minutes to 55 minutes. One to five minutes rest was allowed between work intervals.

There were no statistically significant changes in VO_{2max} after the intervention, and Taylor-Mason (2005) suggested that large inter-individual variation in performance might have influenced this result. Mean power during the 40-kilometer time trial increased by about eight percent after the low-cadence, high-resistance interval training. These findings show that high-resistance interval training during the competitive season can have beneficial influences on the performance of cyclists, especially time trial performance.

Improvements in endurance performance after high intensity training have been linked to an improvement in aerobic and anaerobic metabolic pathways (Tabata *et al.*, 1996; Macdougall *et al.*, 1998; Harmer *et al.*, 2000) and the increase in skeletal

muscle buffering capacity (Weston *et al.*, 1997). Most high-level cyclists use interval training as part of their training for competitions, but it is important to train at the correct intensity with the appropriate volume (Paton and Hopkins, 2004). Harmer *et al.* (2000) found that a seven-week sprint training program (high intensity) reduce anaerobic ATP generation, showing an enhancement in aerobic metabolism, which allows an increase in time to fatigue. Weston *et al.* (1997) also performed a seven-week high-intensity sprint training program on an ergometer (performed on 12 healthy men), and found an increase in glycolytic and oxidative enzyme activity. Weston *et al.* (1997) also found a statistically significant increase in short-term power output (30-second Wingate test) and VO_{2max} .

High-intensity interval training at levels close to VO_{2max} improves the aerobic system, including the VO_{2max} , anaerobic threshold and cycling economy. For already well-trained cyclists, training at a higher intensity will have more beneficial effects, and can further improve submaximal endurance (Paton and Hopkins, 2004).

D. The effect of strength and power training on cycling

Strength training increases the cross-sectional area of skeletal muscles (Tesch, 1988), while the force the muscle is able to generate is directly related to muscle fiber diameter (Fitts *et al.*, 1991). The combination of neuromuscular factors (i.e. coordination), the extent to which a muscle is activated, and muscle cross-sectional area therefore determine muscle function (Sale, 1987; Häkkinen, 1989; Behm, 1995) during strength and power production in sport.

Strength and power training plays an important role in various sports. It aims to improve an athlete's ability to generate high forces against a resistance, or to create a higher work rate and maximal power output. In earlier years, endurance athletes focused mainly on longer distance training, with little emphasis on resistance training. However, coaches and athletes have realised that resistance training form an integral part of any endurance training program (Young, 2006). General physical training has

become more important, giving an athlete a well balanced neuromuscular base (developing necessary fundamentals), from where training can become more specialised and specific closer to the competition phase (Bompa, 1999).

According to Burke (1983), resistance training can improve cycling performance, mainly because dynamic muscular strength plays an important role in improving anaerobic and short-term power output, required during sprints, short climbs, and attacks. Although it is uncertain whether resistance training would improve already trained cyclists, data indicates that resistance training can improve certain aspects (i.e., anaerobic power and endurance capacity) of cycling performance (Tanaka and Swensen, 1998).

Research has shown that resistance training improves leg strength by 35%, and that it improves short-term cycling performance (sprinting for 30 seconds or less) by 29% in untrained individuals (Hickson *et al.*, 1980; O'Bryant *et al.*, 1988). For well-trained endurance athletes, resistance training improved leg strength by 30%, and short term cycling performance by 11% (Hickson *et al.*, 1988). Hickson *et al.* (1988) also showed that resistance training increased long term cycling performance by 20%, measured as time to exhaustion at 80% of VO_{2max} .

Strength training is not likely to improve lactate threshold in already well-trained endurance athletes, although it has been shown to improve lactate threshold in untrained individuals. Jung (2003) reported that resistance training improved running economy by eight percent, which can have a significant influence on overall running performance. This is in agreement with a study done by Paavolainen *et al.* (1999), who found an 8.1% increase in running economy in trained runners after a period of strength training. They found that their nine-week explosive strength training program improved neuromuscular characteristics and therefore muscle power, which resulted in an improved running economy in elite male cross-country runners.

Bishop *et al.* (1999) studied the effects of resistance training on endurance performance and specific muscle characteristics of 21 endurance-trained woman cyclists. 14 cyclists performed resistance training twice a week for 12 weeks, performing five sets (two to eight repetitions) to failure of parallel squats. The control group (n = 7) continued with their normal endurance-training program.

The experimental group showed a statistically significant increase in one-repetition squat strength after six and twelve weeks (35.9%), while the control group improved by 3.7%. However, there were no significant increases in VO_{2max} , lactate threshold, or the average power output during the one-hour cycle test. The reason for the failure in the present study to convert maximal leg strength training to improved cycling performance, might be because of the slow velocity at which the strength training was performed. Another reason might be the movement specificity during strength training so that the improvement in training specific exercise (i.e., the 1RM squat) did not transfer to cycling performance. These findings are in agreement with other studies where it was shown that traditional strength training, (i.e. heavy resistance with low repetition), does not improve a persons' VO_{2max} (Hurley *et al.*, 1984; Hickson *et al.*, 1988; Marcinik *et al.*, 1991; Bishop and Jenkins 1996; Hoff *et al.*, 2002b; Jung, 2003) or anaerobic/lactate threshold (Hoff *et al.*, 2002b). In conclusion, it seems that resistance training can improve a cyclist's sprint performance and cycling economy, but that it is unlikely to cause changes in the other endurance related performance parameters.

Explosive-strength training is a type of resistance training that leads to specific neural adaptations, for instance increasing the rate at which motor units are activated and an increased synchronization of motor unit recruitment, with less hypertrophy than normal strength training (Häkkinen *et al.*, 1985; Sale, 1991; Häkkinen, 1994). This type of training not only improves peak force, but also the rate of force development (Hoff *et al.*, 2002a) and is similar to plyometric training.

Bastiaans *et al.* (2001) studied the effects of a nine-week explosive strength training program in trained cyclists. 14 competitive cyclists were divided into an experimental (n = 6) and a control group (n = 8), with the experimental group replacing 37% of their normal endurance training with explosive-type strength training, while the control group continued with endurance training only. Testing was conducted before, after four weeks, and at the end of the intervention.

The experimental group showed a significant increase in time trial performance (average power output) and in peak power output (during the incremental ergometer test) after four weeks of training while the control group showed no significant changes at this point. There were no additional changes in these outcome variables after nine weeks. The experimental group showed a statistically significantly increase in mean power during the 30-second Wingate test, as well as improved cycling efficiency during the submaximal exercise test.

The significant changes after four weeks in time trial performance and maximal power output (incremental test), show that adaptations in endurance performance might occur faster when normal endurance training is combined with resistance training, than just with normal endurance training alone. However, over the long term, it seems as if explosive strength training does not have an added advantage.

Paton and Hopkins (2004) reviewed the effect of high-intensity training on the performance of endurance athletes, by examining 22 relevant training studies. Studies included high intensity resistance (explosive, weights and plyometrics) and interval training (sport-specific exercises performed with no additional resistance) performed by competitive athletes (including cyclists, runners, swimmers and skiers). Duration and intensity of intervals were classified into submaximal (>10 minutes), maximal (two to 10 minutes), and supramaximal (<two minutes) while the “maximal” refers to the intensity corresponding to the subjects’ maximum oxygen consumption (VO_{2max}). Except for one of the studies, all the research was performed during the non-competitive phase of the athletic season.

Paton and Hopkins (2004) found that maximal and supramaximal intervals both improved endurance performance by three to eight percent at submaximal intensities, while explosive resistance training only showed a 0.3 to one percent increase in endurance performance over the same time period (four weeks), and a 2.9 to 4 percent increase after nine weeks. Peak power output increased by 2.5 to 7 percent after maximum intensity intervals, and only by 1 to 4.7% after supramaximal intervals. Sport-specific resistance training resulted in only a 2.3 to six percent increase in maximum incremental power. The research showed that interval training achieved its effects on endurance performance by increasing VO_{2max} , anaerobic threshold and exercise economy with explosive resistance training having the most profound effect on training economy.

CHAPTER FIVE

PROBLEM STATEMENT

A. Background

It is unknown if plyometric training will have any positive effect on the performance variables of road cycling or mountain biking. Plyometric training is usually related to sports where the body is in contact with the ground, and powerful movements are required to obtain successful movements (i.e., rugby, athletics and netball). Cycling uses predominantly lower body muscles, and is known for continuous flexion and extension in the ankle-, knee- and hip joint.

Most cyclists do not perform extra strength or power training in the gymnasium, but rely on high intensity interval training and hill training to improve their cycling power. However, specifically mountain biking, requires powerful bursts on uneven terrains and therefore one could argue that mountain biking may benefit from explosive type exercises.

Plyometric exercises involve powerful movements, which consist of the lengthening and shortening of a muscle. This is actually a similar movement to that of a cyclist. It has been shown that power endurance and peak power output are two of the most important performance variables in cycling. Thus, any additional training strategy that can improve these variables, should translate to improved cycling performance.

B. Objective of the study

The main objective of the study was to establish if a plyometric training program will improve the aerobic and anaerobic capacities of well-trained cyclists.

C. Specific aims

1. To determine if plyometric training improves the maximal aerobic capacity, namely VO_{2max} , peak power output and peak blood lactate concentration, of cyclists.
2. To determine if plyometric training improves the short-term endurance-power of cyclists during a 5-kilometer time trial.
3. To determine if plyometric training improves the muscle strength and anaerobic power of cyclists.

CHAPTER SIX

METHODOLOGY

A. Study design

In this qualitative experimental study, well-trained cyclists completed a series of tests before and after a plyometric exercise intervention. The subjects had to follow a set program, which consisted of the following four components:

1. Four weeks of strength training in the gymnasium.
2. One week of laboratory exercise tests.
3. 24 plyometric training sessions.
4. Two weeks of follow-up laboratory exercise tests.

B. Subjects

Twenty male cyclists, between the ages of 18 and 40 years, volunteered to take part in the study. Cyclists in the Stellenbosch and Somerset West region, and from the Maties Cycling Club, were personally approached and asked to participate in the study. An appointment was made with each cyclist, where the protocol was explained and where the cyclist had the opportunity to ask questions about the study and test procedures. Cyclists were then asked to read and sign a consent form (Appendix A) before they were finally admitted to the study. All the cyclists had to meet the following inclusion and exclusion criteria:

1. Inclusion criteria

- a) The mountain bikers had to participate in the 2006 Western Province Mountain Biking League. The road cyclists had to be competitive club cyclists in the 2006 cycling season.
- b) Between the ages of 18 and 40 years.

- c) Cycle at least three times a week.
- d) Be able to participate in a four-month intervention program, with three training sessions per week. This included at least two weeks of testing before and after the intervention.

2. Exclusion criteria

- a) Any type of injury, illness or other responsibilities that will influence their performance, or prevent them from participating in the tests or the intervention program.
- b) Cyclists who were involved in a gymnasium training program during the study period.

Of the 20 volunteers, 13 cyclists (nine mountain bikers and four road cyclists) were randomly chosen to participate in the training program (experimental group). An additional three mountain bikers and four road cyclists ($n = 7$) formed the control group. The control group had to continue doing their normal cycle training program during the study period, and no additional exercises were given to them. They were also not permitted to engage in any other type of training, besides cycling. Both the experimental and the control group completed a daily diary (Appendix B). The incentive for the cyclists to complete the program was that they would receive all their test results *pro bono*.

The motivation for including road cyclists in the study, was to increase the sample size as not sufficient numbers of mountain bikers were available to complete the four month intervention program.

C. Experimental overview and procedure

The subjects in the experimental group started off with a month of gymnasium training, which consisted of three training sessions per week. This training prepared

the subjects for the plyometric training program, by improving their overall strength.

For the mountain bikers, testing consisted of four contact sessions. During the first session, which happened during the month of gymnasium training, a VO_{2max} test was completed. The gymnasium training was followed by a week of additional laboratory exercise tests. Subjects visited the laboratory twice during this week, and also completed the outdoor time trial. The road cyclists' testing consisted only of three contact sessions, as they did not participate in the outdoor time trial.

The control group did not participate in the gymnasium training, but followed the same testing procedures as the experimental group. Once again, only the mountain bikers in the control group completed the outdoor time trial.

After the intervention the cyclists had to repeat all the tests, which were completed within two weeks after the intervention. The sequence of the tests is illustrated in figure 6.1. All the kinanthropometry measurements and laboratory tests that were done is part of a standardised fitness evaluation. The field test (an off-road time trial) was developed by the researcher.

All tests (pre- and post-intervention) were done at about the same time of the day. Cyclists were not allowed to take part in any physical activities within the 24 hours prior to the scheduled testing. No caffeine, food, or other stimulants were permitted within two hours of the time trial and the VO_{2max} test. Subjects were instructed to follow their usual diets during the intervention.

Testing and prescribed exercises (strength and plyometric training) were done at the Department of Sport Science, Stellenbosch University, under the supervision of the researcher or a qualified trainer. The researcher is a NSCA accredited strength and conditioning coach and also trained in all aspects of laboratory exercise testing.

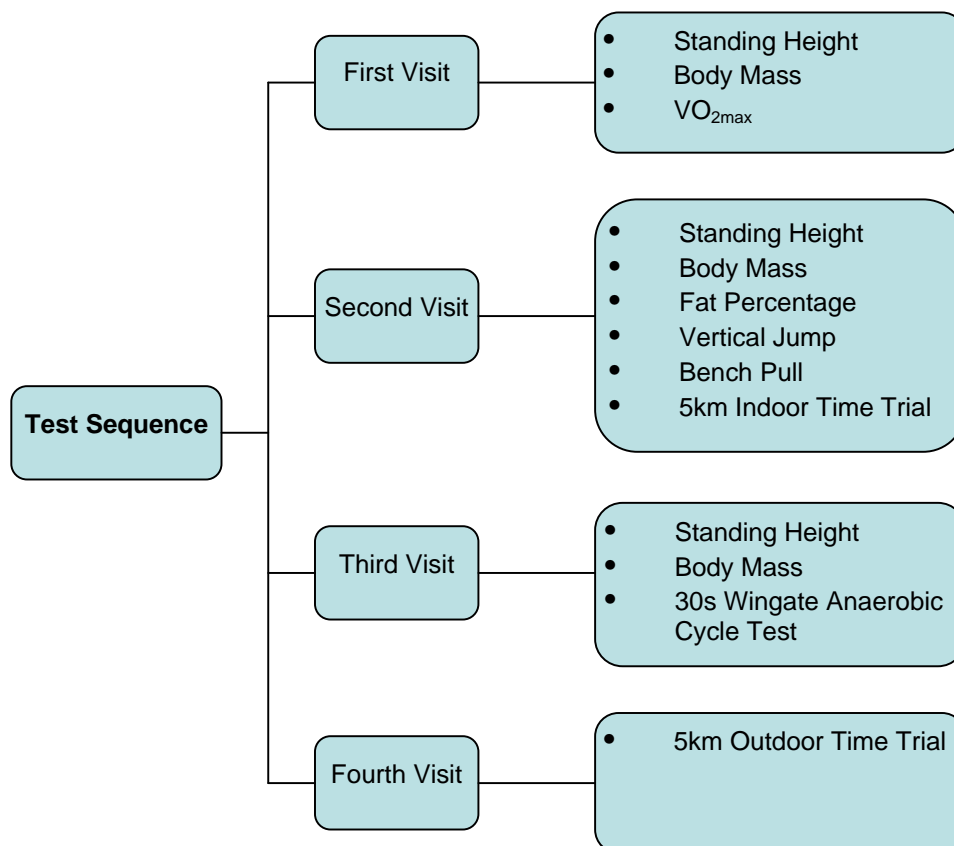


Fig. 6.1: The sequence of pre- and post-intervention testing.

D. Tests and measurements

1. Kinanthropometry

Standing height: Standing height was measured with a stadiometer that was placed in a perpendicular position to the floor. This is done to determine the maximal distance between the ground and the person's vertex. The cyclist was barefoot and stood upright, heels together, with his arms hanging at the sides. His heels, buttocks, and upper part of his back were against the vertical part of the stadiometer with his head in the Frankfort position. The middle line of his body was in line with the

stadiometer behind him. The measurement was taken at the spot where the sliding headplate touched the person's vertex, while he inhaled deeply. The measurement was taken to the closest millimeter (mm).

Body mass: Body mass was measured using an electronic scale (*UWE BW-150* freeweight, 1997 model, Brisbane, Australia). The cyclists were dressed in cycling clothes, and stood barefoot on the scale. A reading was taken to the closest gram (g).

Fat percentage: A bioelectrical impedance analyzer (Bodystat® BCM1000) was used to determine total body fat and fat-free mass. Due to possible interference with the electrical current, the subject had to remove all metallic objects and other electronic devices from his body. The subject was asked to lie supine on his back, with his head flat on the bed for at least 10 minutes. Before the measurement was made, the subject's arms were slightly abducted so that they did not touch the trunk and legs. Legs were separated at least twenty centimeters. The subject was not allowed to move during any stage of the measurement. Electrodes were connected on the right hand side of the body as follows:

- a. The first electrode (red lead electrode) was placed just behind the middle finger.
- b. The second electrode (black lead electrode) was placed on the wrist next to the ulnar head.
- c. The third electrode (red lead electrode) was placed just behind the second toe.
- d. The fourth electrode (black lead electrode) was placed on the ankle, between the medial and lateral malleoli.

All these anatomical sites were cleaned with alcohol swabs and dried with cotton wool, before electrodes were attached. After this the cable pairs were connected to all the electrodes. An electrical current of 50 hertz were applied, which measured the resistance of the body tissue against the current. Body fat and fat free mass was

expressed as a percentage.

2. Vertical jump test

The purpose of the vertical jump test was to measure the cyclist's vertical leg power. The subject stood with his dominant side against the wall. He then reached with his hand (closest to the wall) to touch as high as possible, while the heels remained on the ground. This height was recorded as the reach height. The cyclist then dipped the fingertips of his dominant hand in chalk and then, from a two-footed take off position jumped as high possible and touched the board. The cyclist was allowed to flex his knees and hips and use his arms to gather momentum for the jump. The cyclist was not allowed to take a step or double jump. The height reached with the jump was recorded as the jump height. The difference between the jump height and reach height was calculated as the cyclist's vertical jump score. A practice jump was given before the test was done. The best of two trials was taken to the closest 0.5-centimeter.

3. Bench pull

The bench pull exercise was done to measure arm and shoulder pulling strength. In this test the subject was required to use the muscles in his arms, back of the shoulder, and upper back to pull the bar to his chest. These are the same muscles used when a cyclist pull on his handle bar. During this test, the subject was required to lie prone, on his stomach, on the bench. The bench height was adjusted to enable full extension of the arms. A 20-kilogram bar was used, with an added ten kilograms on each side. The total weight was therefore 40 kilograms. The subject had to take a shoulder wide pronated grip on the bar, and pull it up to the bench. He had to keep his elbows pointing outwards with his chest on the bench during the entire movement. A successful repetition was recorded when the subject pulled the bar until it touched the bench. During the downward movement, he had to straighten his arms before doing the next repetition. The subject had to maintain a continuous movement

sequence, with no rest in between efforts, to perform as many repetitions as possible until he was fatigued. The subject did one repetition as a practice effort before starting the actual test. The number of successful repetitions was recorded as the cyclist's final score.

4. Aerobic capacity test

A progressive incremental exercise test to exhaustion was performed on a cycle ergometer to determine the subject's maximal aerobic capacity.

Cycle ergometer: An electronically braked cycle ergometer (Lode Excalibur Sport, Quinton, Seattle, WA) was used for the test. The ergometer's seat and handle bar position were adjusted to suit each cyclist. These measurements were also recorded for future testing.

Gas analysis: Breath-by-breath gas measurements were continuously recorded during the warm-up and throughout the incremental test to exhaustion. Expired gases, flow and volumes were sampled through the turbine flow meter, a gas sampling line and analyzed by a cardio-pulmonary metabolic system (Cosmed Quark b², Rome, Italy). Heart rate was measured through biotelemetry (POLAR®, Polar Electro Oy, Finland) and also recorded by the metabolic system. The gas analyzers were calibrated prior to each test with atmospheric gas and known gas concentrations (16% O₂, 4% CO₂, balance N₂) and the turbine flow meter was calibrated with a three-liter calibration syringe.

Lactate analysis: Whole blood lactate concentrations were measured with an automated blood lactate meter (Lactate Pro, Arkray Inc., Kyoto, Japan). Blood was sampled using a finger prick lancet device (Softclix®, Boehringer Mannheim). Samples were taken before the start of each test, on completion of the test and during each workload until a lactate concentration of four mmol.L⁻¹ or higher were registered. With each blood sample, the subject's fingertip was cleaned with an alcohol swab,

and after the first drop of blood was wiped off with cotton wool, the next drop of blood was sampled on the lactate strip. The lactate threshold was defined as the VO_2 where the blood lactate concentration rose one $mmol.L^{-1}$ above the baseline blood lactate concentration (Coyle *et al.*, 1983).

Incremental test: A progressive incremental protocol to exhaustion was used to determine maximum aerobic capacity and maximum heart rate (HR_{max}). Peak power output (PPO) and the power output at lactate threshold were also determined during the test.

Subjects warmed up at a workload of 100 watts for a period of five minutes. During this time gas analysis data was used in order to determine the subject's cycling economy. After the warm-up period, a two-minute recovery was allowed, after which the incremental test commenced. During the rest period, the facemask was removed so the cyclist could drink water. The cyclist was required to keep the cadence constant between 80 and 100 rpm through both the warm-up and the test. The test commenced at an initial workload of 120 watts for the first minute. Thereafter, the workload was increased by 30 watts every two and a half minutes until the cyclist could not maintain a cadence of 80 rpm.

The averages of the highest, consecutive ten second values of VO_2 , VE, RER and heart rate during the final workload of the incremental test were calculated as the maximum values. Peak power output was calculated using the following formula (Kuipers *et al.*, 1985):

$$\text{Peak power output} = W_f + (t / 150 \cdot 30) \dots \dots \dots 6.1$$

Where W_f is the last completed workload, while t is the time in seconds in the uncompleted workload. The peak power output was used to calculate the power-to-weight ratio.

5. 5-km time trial (TT)

Cyclists performed a five-kilometer time trial on the Kingcycle (Kingcycle™, High Wycomb, UK). The purpose of the time trial was to measure muscle endurance and cadence over a short distance, therefore the time trial was only five kilometers long. The rolling resistance of the machine was calibrated for each individual cyclist. The flywheel provided the back wheel with the necessary resistance, and the crank and flywheel sensors picked up the cyclist's cadence and wattage, respectively. The cyclist wore a heart rate belt (POLAR®, Polar Electro Oy, Finland) and a receiver provided the interface with the heart rate data (beats per minute). The cyclists received feedback during the time trial via the Kingcycle interface in the form of cycling speed, elapsed time, distance completed and heart rate. After an eight-minute warm-up, a two-minute break was given to the cyclist. After this, the subject had to complete the five kilometers in the shortest possible time. Time trial performance was calculated as the average power output (W), speed (km.h⁻¹), cadence (rpm), power-to-weight ratio, and the time (s) it took to finish the test.

6. Anaerobic capacity test

The 30-second Wingate test was done on an electronically braked ergometer (Lode Excalibur Sport, Quinton, Seattle, WA) to determine the cyclist's maximum anaerobic capacity and anaerobic power. The torque factor of the ergometer was set at 0.95. A ten-minute warm-up was done at a workload of 80 watts; thereafter the cyclist rested for one minute before the test commenced. The test started with a one-minute countdown during which the cyclist sustained a cadence of 100 rpm at 100 watts. Cyclists were instructed to go as hard and fast as possible from the start and to maintain this maximal effort for 30 seconds. They were also asked to remain seated throughout the test. After the first test, the cyclist continued cycling for another 10 minutes at 80 watts, before they repeated the test. The power-to-weight ratio, fatigue index, peak and average power output were calculated from the raw data. Using the peak power output as reference, the best of the two tests were used to quantify the

anaerobic capacity.

7. Field test

A 4.4-kilometer mountain bike route was marked out at the Coetzenburg sports grounds. The aim was to set a challenging route, which included steep, short and long climbs. The route included a long steady climb in the beginning and middle, with steep and shorter climbs spread throughout the course. It also included a technical part, where the subjects needed to make use of their mountain biking skills. The route was well known to all of the cyclists (many of them train regularly on this part of the mountain), and it was also explained to them by using a map. Chalk marks were laid out on the route to assist the cyclists with their direction.

The cyclist completed the field time trial individually and was instructed to complete the route in the shortest possible time. The time to complete the route (to the nearest second) was taken with a stopwatch. Only the mountain bikers in both the control and experimental group had to complete the mountain biking route.

E. Intervention

During the first four weeks of the training program, the subjects in the experimental group had to complete a gymnasium-training program consisting of 12 sessions (Appendix C). The gymnasium sessions were included to improve the overall body strength of the subjects before starting with a plyometric program. All gymnasium sessions lasted between 45 and 60 minutes, and subjects had to complete all 12 sessions. A maximum of three cyclists trained together per session. At least 36 hours of rest was allowed between sessions.

The plyometric training program (Appendix D) consisted of 24 sessions, and was completed over eight to nine weeks. Subjects had to complete at least 22 of the 24 sessions, without missing more than two sessions consecutively. Subjects rested

between 36 and 48 hours between sessions, and two to three minutes between sets. This allowed for a 1:5 to 1:10 work-to-rest ratio between sets, allowing enough recovery to ensure a maximal effort with the next set. Individual sessions never exceeded 45 minutes, and a maximum of five cyclists trained together in one session. Subjects were allowed to do moderate cycling training on the same day of their plyometric session.

The volume of training was expressed as the number of repetitions and sets done during the plyometric session. Lower body plyometrics were given as the number of foot contacts per workout. The volume started at 80-foot contacts (beginner load), and progressed up to 140-foot contacts per session at the end of the intervention (advanced load). All exercises were divided into three difficulty levels (low, medium, high) to define the intensity. The exercise intensity progressed from low to high over the 24 sessions. Boxes used during box drills and depth jumps, were made of wood, and the box heights ranged between 30 and 50 centimeters. The boxes and the landing areas had non-slippery surfaces, which reduced the risk of injury. Training was done either on grass fields, or an indoor hall, which allowed for 30 meters of training space. Upper-body plyometrics and the plyometric sit-up were done with a 1-kilogram medicine ball during the first four weeks, and a 2-kilogram ball during the last four weeks.

By systematically increasing the intensity, decreasing the amount of different exercises per session, and increasing the amount of repetitions progressively, the subjects adapted to plyometric training safely and without any injuries. To prevent injuries, exercises were done on grass and on a shock absorbent surface. Subjects were asked to wear proper footwear, with a non-slip sole, and proper ankle support.

During the first two weeks of the intervention, the main focus was on maintaining balance and executing the exercises with the correct technique. During lower-body plyometrics a proper landing technique is important, with the shoulders over the knees, and proper flexion in the ankles, knees and hips. This was done to prevent

injuries and ensure effective training. During the entire training program a strong emphasis was placed on safety and correct techniques. Sessions began with a dynamic warm-up specific to plyometric exercises, which included a jog and side shuffles, for an estimated ten minutes. After the session, subjects were allowed five to 10 minutes for stretching.

Subjects had to keep a daily diary of their training outside of the plyometric sessions, for the entire intervention period. This included any type of exercise that might influence their test results.

F. Control group

The control group did not participate in the gymnasium training or any of the plyometric exercise sessions. The control group followed the same testing procedures as the experimental group, and completed the tests in the same order. Within four weeks after finishing the VO_{2max} test, they completed the week of laboratory tests and the field time trial. During the intervention period the control group continued with their normal cycling training and also completed a daily diary similar to the experimental group. None of the cyclists followed a gymnasium training program during the intervention. After an eight-week training period the control group repeated the laboratory tests all within two weeks.

G. Statistical analysis

Descriptive data are expressed as means \pm standard deviation (SD), unless otherwise specified. The effects of the intervention program were assessed with a 2 x 2 Anova for independent groups. Statistical differences in the changed scores of all the outcome variables were determined with Mann-Whitney U-tests. Pearson correlation analysis was performed to test for the association between selected variables. Statistical significance was set at $p < 0.05$.

CHAPTER SEVEN

RESULTS

A. Introduction

The main aims of this study were to determine if a plyometric training program would have an effect on the cycling performance of trained cyclists. To this end, cyclists were evaluated on a number of laboratory tests, as well as a field test.

B. Subject characteristics

Subjects were randomly divided into an experimental and control group. Of the total group, 13 were mountain bikers and seven were road cyclists. There were no statistically significant differences with regards to their age, height, body mass and body fat percentage (Table 1) at baseline testing. There were also no significant changes in the subjects' height, body mass or percentage body fat after the intervention.

Table 7.1: Personal characteristics of the experimental and control groups during baseline testing ($p > 0.05$).

| | Experimental | | Control | |
|-------------|-----------------|-----------|------------------|-----------|
| | Mean \pm SD | Range | Mean \pm SD | Range |
| n | 13 | | 7 | |
| Age | 24.2 \pm 5.04 | 19 - 35 | 23.9 \pm 4.14 | 19 - 31 |
| Height (cm) | 178 \pm 5.10 | 170 - 186 | 182.4 \pm 5.49 | 171 - 188 |
| Weight (kg) | 77.7 \pm 5.72 | 67 - 87 | 75.6 \pm 7.83 | 61 - 86 |
| Fat % | 11.5 \pm 2.62 | 8 - 17 | 11.2 \pm 2.08 | 9 - 15 |

C. Maximal exercise capacity

1. Experimental versus control group at baseline

Table 2 shows that there were no significant differences in any of the VO_{2max} test variables between the experimental and control group during baseline testing. All the tests met the criteria for a maximal test as outlined in the methods. Although the absolute and relative VO_{2max} -values of the control group were slightly higher compared to the experimental group, these differences did not reach statistical significance ($p = 0.08$ and 0.09 , respectively). The VO_{2max} -values (above $55 \text{ mL.kg}^{-1} \cdot \text{min}^{-1}$) further indicate that the subjects were well-trained cyclists.

Table 7.2: The maximum exercise capacity of the experimental and control group during baseline testing ($p > 0.05$).

| | Experimental | | Control | |
|---|------------------|-----------|-------------------|-----------|
| | Mean \pm SD | Range | Mean \pm SD | Range |
| n | 13 | | 7 | |
| VO_{2max} (L.min^{-1}) | 42.8 ± 2.68 | 39 - 48 | 46.4 ± 6.13 | 40 - 57 |
| VO_{2max} ($\text{mL.kg}^{-1} \cdot \text{min}^{-1}$) | 56.7 ± 3.59 | 52 - 64 | 61.4 ± 8.22 | 48 - 71 |
| HR_{max} (bpm) | 192.6 ± 5.35 | 187 - 204 | 192.3 ± 8.2 | 184 - 209 |
| VE_{max} (L.min^{-1}) | 165 ± 15.15 | 132 - 185 | 174.6 ± 20.55 | 152 - 217 |
| RER_{max} | 1.2 ± 0.04 | 1.2 - 1.3 | 1.2 ± 0.05 | 1.1 - 1.3 |
| LT (% VO_{2max}) | 70.9 ± 9.87 | 51 - 82 | 67.9 ± 7.24 | 56 - 76 |
| PPO (W) | 364 ± 28.06 | 314 - 402 | 358.9 ± 56.16 | 254 - 422 |
| La_{max} (mmol.L^{-1}) | 13.4 ± 2.16 | 10 - 17 | 14.1 ± 1.08 | 12 - 16 |
| PPO/Weight (W.kg^{-1}) | 4.7 ± 0.38 | 4.3 - 5.4 | 4.8 ± 0.83 | 3.3 - 5.7 |
| PO_{LT} /Weight (W.kg^{-1}) | 3 ± 0.58 | 1.9 - 3.6 | 2.9 ± 0.43 | 2.4 - 3.7 |

HR = heart rate

VE = minute ventilation

LT = lactate

PPO = peak power output

2. Road cyclists versus mountain bikers at baseline

There were no significant differences between the road cyclists and mountain bikers in any of the VO_{2max} variables during baseline testing (Table 3).

Table 7.3: The maximum exercise capacity of the mountain bikers and the road cyclists during baseline testing ($p > 0.05$).

| | Mountain bike | | Road | |
|---|-------------------|-------------|-------------------|-----------|
| | Mean \pm SD | Range | Mean \pm SD | Range |
| n | 12 | | 8 | |
| VO_{2max} (L.min ⁻¹) | 44.1 \pm 4.79 | 39 - 57 | 44 \pm 4.11 | 40 - 52 |
| VO_{2max} (mL.kg ⁻¹ .min ⁻¹) | 59.2 \pm 5.56 | 52 - 69 | 57.1 \pm 6.58 | 48 - 71 |
| HR _{max} (bpm) | 194.3 \pm 7.11 | 187 - 209 | 189.9 \pm 3.76 | 184 - 195 |
| VE _{max} (L.min ⁻¹) | 171.8 \pm 16.27 | 151 - 217 | 163.2 \pm 18.68 | 132 - 185 |
| RER _{max} | 1.2 \pm 0.05 | 1.1 - 1.3 | 1.2 \pm 0.03 | 1.2 - 1.3 |
| LT (% VO_{2max}) | 41.7 \pm 5.73 | 33.6 - 51.6 | 39.2 \pm 6.78 | 28 - 47 |
| PPO (W) | 360.3 \pm 45.47 | 254 - 422 | 365 \pm 28.41 | 326 - 414 |
| La _{max} (mmol.L ⁻¹) | 13.2 \pm 1.79 | 10 - 16 | 14.4 \pm 1.84 | 12 - 17 |
| PPO/Weight (W.kg ⁻¹) | 4.7 \pm 0.61 | 3.3 - 5.5 | 4.7 \pm 0.5 | 4.1 - 5.7 |
| PO _{LT} /Weight (W.kg ⁻¹) | 3.1 \pm 0.4 | 2.5 - 3.6 | 2.7 \pm 0.62 | 1.9 - 3.7 |

HR = heart rate

VE = minute ventilation

LT = lactate

PPO = peak power output

3. Effect of plyometric training on maximal exercise capacity

Figure 7.1 shows the effect of the plyometric training program on VO_{2max} , peak power output, VO_2 at lactate threshold, and maximal lactate. The experimental group demonstrated a 1.9% increase in absolute VO_{2max} and a 2.9% increase in relative VO_{2max} , but these changes were not statistically significant. There was a statistically significant interaction effect for the relative VO_{2max} -values, however, this was unfortunately not the result of the plyometric training program. It is evident from figure 7.1a that there was a significant decrement in the performance of the control group after the intervention. This low average value can be attributed to a very low VO_{2max} -

value of one subject. There were no statistically significant interaction effect for HR_{max} , VE_{max} , peak power output or VO_2 at the lactate threshold.

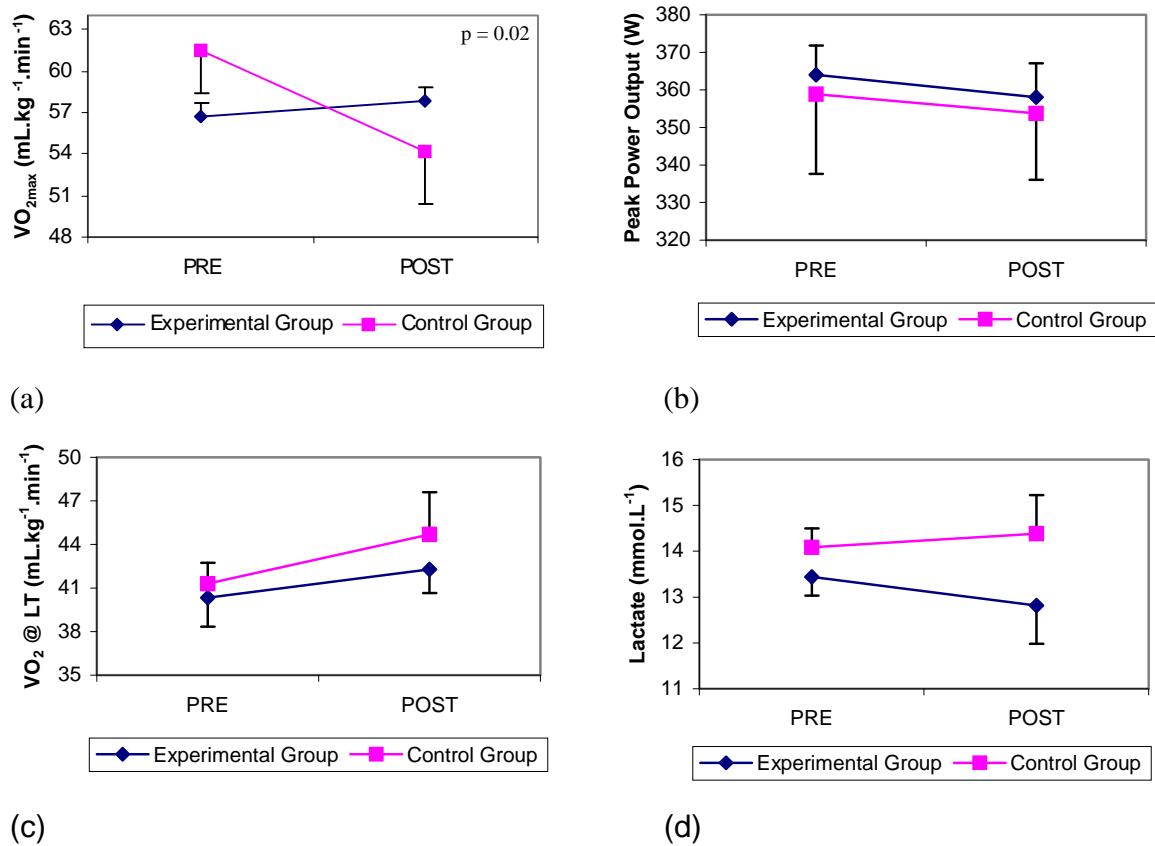


Figure 7.1: The effect of the intervention program on (a) VO_{2max} , (b) peak power output, (c) VO_2 at lactate threshold and (d) maximal blood lactate concentration.

D. 5-kilometer laboratory time trial

1. Experimental versus control group at baseline

During baseline testing there were no significant differences between the experimental and control groups' average heart rate (bpm), and time (s) to complete the time trial (Table 7.4). Although the experimental group completed the time trial with a faster time at a lower average heart rate compared to the control group, the

difference was not statistically significant. The same observation was made for the other performance variables.

Table 7.4: 5-kilometer laboratory time trial performance of the experimental and control group during baseline testing ($p > 0.05$).

| | Experimental | | Control | |
|------------------|------------------|-----------|-------------------|-----------|
| | Mean \pm SD | Range | Mean \pm SD | Range |
| n | 13 | | 7 | |
| Average HR (bpm) | 179.1 \pm 6.83 | 168 - 188 | 178.7 \pm 8.3 | 170 - 196 |
| Time (s) | 400 \pm 22.87 | 373 - 460 | 404.7 \pm 16.56 | 372 - 418 |

HR = heart rate

2. Road cyclists versus mountain bikers at baseline

There were no significant differences in average heart rate (bpm), and time (s) to complete the time trial between the road cyclists and the mountain bikers at baseline testing (Table 7.5).

Table 7.5: 5-kilometer laboratory time trial results between the mountain bikers and the road cyclists during baseline testing.

| | Mountain bike | | Road | |
|------------------|-------------------|---------------|-------------------|-----------|
| | Mean \pm SD | Mean \pm SD | Mean \pm SD | Range |
| n | 12 | | 8 | |
| Average HR (bpm) | 177.1 \pm 6.60 | 168 - 188 | 182.14 \pm 7.47 | 174 - 196 |
| Time (s) | 397.8 \pm 24.69 | 372 - 460 | 407.5 \pm 11.06 | 392 - 418 |

HR = heart rate

3. Effect of plyometric training on time trial performance

There were no statistically significant intervention effects for time trial time (s) or heart rate, indicating that the plyometric training program had no significant effect on 5-kilometer time trial performance.

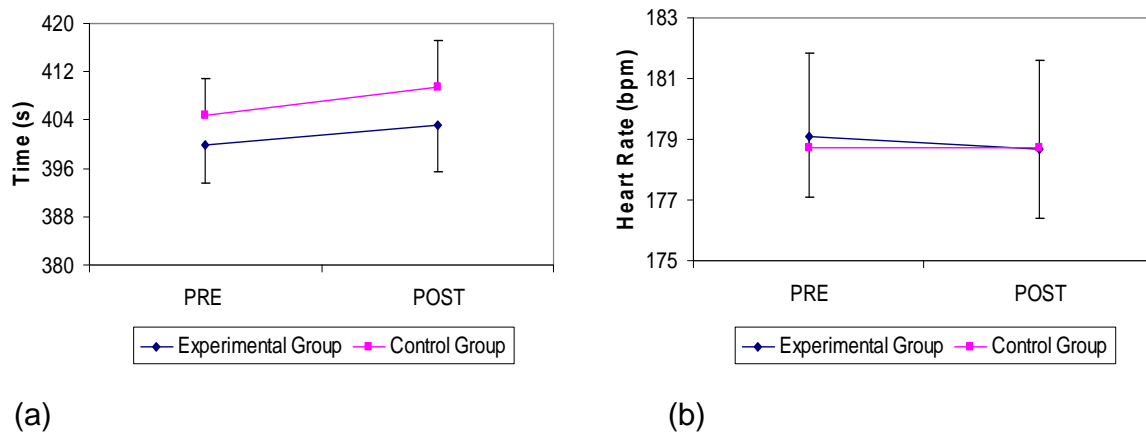


Figure 7.2: The effect of the intervention program on (a) time and (b) average heart rate during the 5-kilometer laboratory time trial.

E. 30-second Wingate test

1. Experimental versus control group at baseline

Table 7.6 shows that the main outcome variables of the anaerobic capacity test did not differ significantly between the experimental and control groups. The peak power output of the control group was slightly higher than the experimental group, but the reverse was true for mean power output.

Table 7.6: The anaerobic capacity of the experimental and control group at baseline testing ($p > 0.05$).

| | Experimental | | Control | |
|-----------------------|-------------------|-------------|---------------------|-------------|
| | Mean \pm SD | Range | Mean \pm SD | Range |
| n | 13 | | 7 | |
| PPO (W) | 1396 \pm 250.41 | 1145 - 2081 | 1401.3 \pm 242.70 | 1109 - 1838 |
| Mean PO (W) | 855.2 \pm 87.85 | 750 - 1044 | 851.1 \pm 101.06 | 748 - 1037 |
| Fatigue Index (W.sec) | 34.1 \pm 11.22 | 23 - 60 | 33.2 \pm 8.31 | 22 - 44 |

PPO = peak power output

PO = power output

2. Road cyclists versus mountain bikers at baseline

Although the mountain bikers had higher peak power output and mean power output during the Wingate test, the values were not statistically significantly higher compared to the control group (Table 7.7).

Table 7.7: The anaerobic capacity of the mountain bikers and the road cyclists during baseline testing ($p > 0.05$).

| | Mountain bike | | Road | |
|-----------------------|---------------------|-------------|---------------------|-------------|
| | Mean \pm SD | Range | Mean \pm SD | Range |
| n | 12 | | 8 | |
| PPO (W) | 1442.8 \pm 276.40 | 1145 - 2081 | 1330.4 \pm 171.12 | 1109 – 1534 |
| Mean PO (W) | 864.5 \pm 100.54 | 750 - 1044 | 837.6 \pm 74.94 | 748 – 934 |
| Fatigue Index (W.sec) | 35.3 \pm 11.80 | 23 - 60 | 31.6 \pm 6.89 | 22 – 44 |

PPO = peak power output

PO = power output

3. Effect of plyometric training on Wingate performance

Figure 7.3 shows that there were a 4.8% improvement in peak power output ($p = 0.06$) and a 0.9% change in mean power in the experimental group after completion of the plyometric training program. None of these changes, however, were statistically significant although the changes in peak power output of the experimental group bordered on statistical significance. Eight of the 13 subjects thus improved their anaerobic capacity. In both instances, the performance of the control group decreased after the intervention. In fact, the decrease in mean power was statistically significant ($p = 0.02$). The interaction effect for peak power output was also close to reach statistical significance ($p = 0.07$).

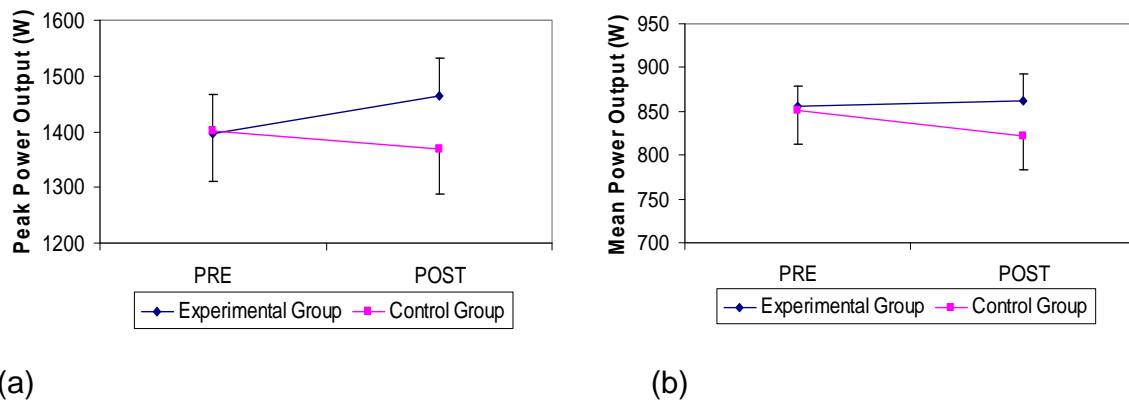


Figure 7.3: The effect of plyometric training on the (a) peak power output and (b) mean power output from before to after the intervention ($p > 0.05$).

F. 4.4-kilometer field time trial

1. Experimental versus control group at baseline

Only the mountain bikers completed the field time trial. There were nine mountain bikers in the experimental group and three in the control group. During baseline testing the experimental group performed better than the control group, with an average time of 793.44 (s), compared to the 819 seconds ($p = 0.69$).

2. Effect of plyometric training on field time trial performance

There were no significant changes in the outdoor time trial in either the experimental or control group after the intervention (figure 7.4). However, both the experimental and control group improved their times (1.6% and 7.1%, respectively; $p > 0.05$).

It should be noted that the control group only consisted of three riders, which implies that mean changes in performance would be significantly influenced by an extreme value. The fact that the control group seemingly improved their performance, was thus the result of one cyclist who either did not perform well during the initial tests, or who improved his performance significantly during the follow-up tests.

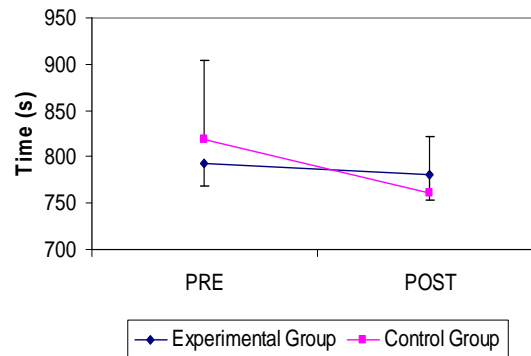


Figure 7.4: The effect of plyometric training on outdoor time trial performance ($p > 0.05$).

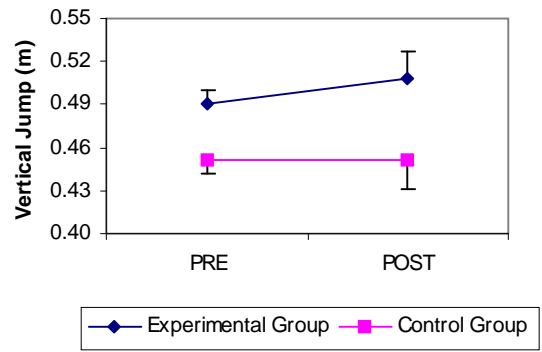
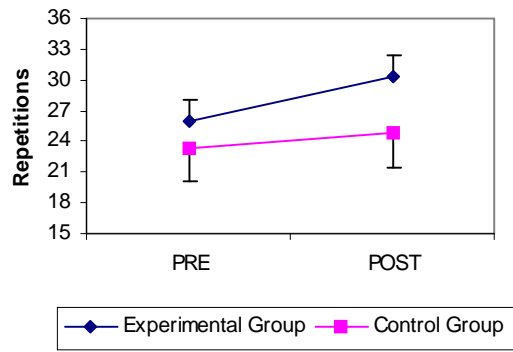
G. Strength and explosive power

1. Experimental versus control group at baseline

The bench pull test was an estimate of upper body strength, while the vertical jump test measures leg power. There were no significant differences between the experimental and control groups' vertical jumping height (0.49 versus 0.45 centimeter) or bench pull (26 versus 23.29 repetitions) during baseline testing ($p > 0.05$).

2. Effect of plyometric training on strength and power

Figure 7.5 show that there was a significant increase of 16.8% in bench pull performance ($p = 0.009$) and a 4.1% change in leg power in the experimental group. The latter change was not statistically significant. Ten out of 13 subjects improved their upper body strength, while seven of the 13 subjects improved their explosive leg power. There were no statistically significant changes in the strength and power of the control group.



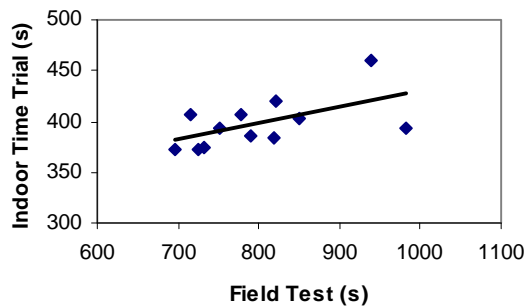
(a)

(b)

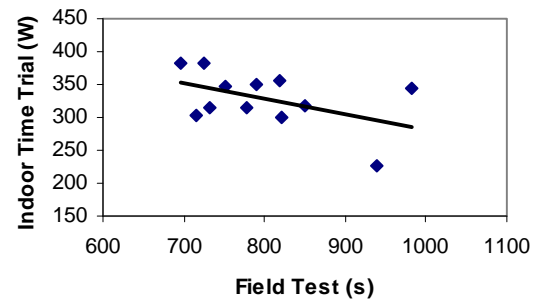
Figure 7.5: The effect of plyometric training on (a) bench pull and (b) vertical jump performance.

H. Relationship between performance outcomes

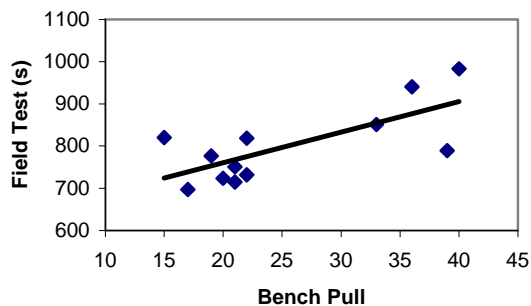
As presented in figure 7.6, there was a strong correlation ($r = 0.57$) in the performance of the cyclists during the indoor time trial (seconds) and the outdoor time trial (seconds), and a moderate correlation ($r = 0.47$) between indoor time trial (watts) and the outdoor time trial (time). There was also a strong correlation ($r = 0.72$) between the outdoor time trial (time) and upper body strength (bench pull repetitions).



(a)



(b)



(c)

Figure 7.6: Correlations between the (a) indoor and outdoor time trial time, (b) outdoor time trial (time) and indoor time trial (watts), and the (c) outdoor time trial and the bench pull test.

CHAPTER EIGHT

DISCUSSION

A. Introduction

There is a lack of studies on the effect of different types of explosive strength training on the physiological performance of cyclists, especially mountain bikers. The effects of plyometric training on other sports (i.e. athletics, running and volleyball) are well-known. Only one study, Paton and Hopkins (2005), have studied the effects of plyometric training on the performance of competitive cyclists, by combining explosive and high-resistance training. Therefore, the comparison between this study and other similar research studies is novel, and will provide a different perspective to the training of different physiological systems in cycling.

B. The reason why plyometric training can benefit cycling

Cyclists are constantly searching for ways to improve their speed and power. A cyclist's ability to generate high power outputs is often one of the most important determinants of success. High intensity interval training is a common training method used to improve power however, coaches and trainers are constantly searching for new and possibly better methods. Plyometrics has been shown to improve explosive power (Potach and Chu, 2000; Bender, 2002), speed (Pettitt, 1999) and explosive reactivity (Archer, 2004). However, this type of training is not normally used for training power in cyclists.

If plyometric training is added to a cycling program during the correct time of the season, it might result in additional improvements in overall cycling performance. Paton and Hopkins (2005) found that by combining high resistance cycling with explosive exercises in trained cyclists, it can increase the exercise efficiency and aerobic power. Both these factors are important determinants of cycling success.

C. Reflections on the findings of this study

After the plyometric training program all the subjects, experimental and control group, completed the same exercise tests performed before the intervention period. These results were compared to each other (pre to post intervention), to determine if the plyometric exercises had any influence on the performance variables measured during the testing. The plyometric training program was performed during the cyclists' pre-season.

The only statistically significant difference ($p < 0.02$) between the experimental and control group during the VO_{2max} test, was the relative VO_{2max} -value, however this was not because of the plyometric training program. There was a slight increase (1.9%), from 56.7 to 57.8 $mL \cdot min^{-1} \cdot kg^{-1}$, in the experimental group, while the control groups' VO_{2max} -value decreased (11.7%) from 61.4 to 54.2 $mL \cdot min^{-1} \cdot kg^{-1}$. The decrease in the control groups' value, rather than the slight increase in the experimental group resulted in a significant interaction effect. However, this was the result of an outlier in the control group during the post-intervention tests. Therefore it must be concluded that the plyometric training program did not significantly improve the cyclists' aerobic power.

Peak power output showed a slight decrease, 1.6% and 1.4% respectively, in both the experimental (from 364 to 358 W) and control (from 359 to 354 W) group. These changes were not statistically significant ($p > 0.05$). The explanation for this decrease might be because of the high volume of cycling training the cyclists went through during this phase of the season, resulting in similar peak power outputs. During pre-season, cyclists (even mountain bikers) aim to establish a solid basic endurance capacity (also called "a base"). Therefore, the lack of training at high intensities (i.e. above the lactate threshold), can explain the absence of any changes in PPO.

For both the experimental and control groups, there were no statistically significant improvements in the five-kilometer indoor time trial ($p > 0.05$). In a previous study,

Bastiaans *et al.* (2001) also found no statistically significant differences (between experimental and control groups) in one-hour time trial performance after a nine-week explosive strength training program in 14 competitive cyclists.

Successful time trial performance relies heavily on good pacing strategies, therefore experience plays a big role. This is true for both field and laboratory time trial performance. The cyclists participating in this study did not have the necessary experience to perform optimally during this test, since most of them have not performed an indoor five-kilometer time trial prior to the study. Therefore, the subjects might have followed different strategies, resulting in different performances between the pre- and post-intervention. The reasons for selecting a relatively short (five kilometer) TT, instead of a 20 or 40 km TT, were twofold. On the one hand it was argued that a shorter distance may be a better reflection of the explosive power what is needed by mountain bikers, while the longer distances placed too much emphasis on endurance. Secondly, it was thought there would be less tactics in a short test (i.e. that it would more or less require an all-out effort) and that the lack of experience would be minimised.

Both the mean and peak power output during the 30-second Wingate test showed a positive trend in the experimental group, when compared to the control group. The mean power output in the experimental group increased from 855.2 to 862.5 W (0.9%), while the control groups' mean power value decreased from 851.1 to 821.4 W (3.5%). This effect was borderline to a statistically significant difference ($p = 0.07$). This may suggest that the experimental group maintained their ability to sprint for 30-seconds, while the control group lost some of their ability.

The experimental groups' peak power output increased from 1396 to 1463.4 W (4.8%), while the control groups' value decreased from 1401.3 to 1368 W (2.4%). Although the peak power output did not result in a statistically significant change ($p = 0.06$), there was an indication that the plyometric exercises led to an improvement in the experimental groups peak power performance.

Training to improve sprinting power is usually not the main focus during the preseason phase of the cycling season, since the emphasis is on the improvement of endurance. It is therefore not uncommon that cyclists' sprinting ability actually decreases during this period. The fact that the experimental group were able to maintain their mean power and even slightly improve their PPO, suggests that the plyometric training program may have helped the cyclists to maintain most of their sprinting ability after the competition season. This means that cyclists would have a solid anaerobic capacity from which they can work from as soon as the season reaches its more critical competition phase.

There were only slight, but not statistically significant improvements in the time trial performance of the experimental group. This is a surprising finding, because it was expected that the mountain bikers would perform better just for the fact that they have been in training for at least two months. Again, perhaps if the time trial was of longer duration so that more stress was placed on their cardiorespiratory systems (i.e. endurance capacity), the effects of the training, including the plyometric training, would have been more evident.

The experimental group showed a statistically significant increase in upper body strength. Their bench pull repetitions increased from 26 to 30.4, showing an 16.9% increase. The control group only showed a 6.9% increase (from 23.3 to 24.9). This result shows that the plyometric exercises used during the intervention significantly improved the upper body strength of the subjects.

The vertical jumping height for the control group remained the same, while the experimental group showed a 4.1% increase in vertical jumping height (from 0.49 to 0.51 cm). The cyclists taking part were already well-trained, and thus may explain the small changes in leg power. This is similar to the subjects in the study done by Kyröläinen *et al.* (2005), who found no changes in muscle-fiber type or size after plyometric training.

One would expect that plyometric training would mainly influence type II muscle fibers, as these fibers are used for short, high intensity contractions. As cycling is mostly an endurance sport, it is expected that most cyclists would have predominantly type I muscle fibers. Whether this is also true for mountain bikers, is not known. It was therefore surprising that Malisoux *et al.* (2006) reported that type I MHC responded better to plyometric training than type II MHC. This means that the functional ability of the type I fibers would improve and become more fast contracting and more powerful. This may, in part, explain the improvements in upper and lower body strength of the experimental group.

D. Reasons for the limited effect of plyometric training

1. Amount of sessions

All the subjects in the experimental group completed 24 plyometric training sessions over a period of eight to nine weeks. The subjects completed a 12-session (four weeks) gymnasium training period before starting with the plyometric training sessions. This strength training base might not have been long enough to prepare the cyclists with the necessary strength to perform powerful movements like plyometrics. This might have delayed the adaptation period of the subjects when the plyometric intervention started, resulting in a much slower progression in plyometric exercises (intensity and volume).

According to Potach and Chu (2000), plyometric programs ranging between six and ten weeks, training two to four times per week, are sufficient to elicit positive training effects. Therefore, the amount of sessions used in this study seems to be enough to reach the necessary results. However, because cyclists are not use to this type of powerful movements, having a high impact with the ground, more sessions might have been needed, to afford the cyclists sufficient time to improve.

2. Types of exercises

Lower body, upper body, and trunk plyometrics were used during this study. The exercises started at a very low intensity, giving the subjects enough time for adaptation. There are not a lot of plyometric exercises which have movement sequences similar to a cycling movement, and therefore the exercises performed during the plyometric training program were not cycling-specific. However, care was taken to stimulate the muscles that are primarily involved in the cycling action (Gregor and Conconi, 2000).

3. Time of season

The plyometric intervention period was performed during the cyclists' preseason preparation. This allowed the subjects to have enough time to perform these exercises without having a marked influence on their normal training program. To perform a similar training program during a cyclists' competition phase, might influence the cyclist's interval training program, and not allow enough time for recovery between these different sessions. When a cyclist is used to this type of training (plyometrics), it can be incorporated into their training for the competition phase. Training can be limited to twice a week, which will allow the cyclist enough time for his regular program. As this is the phase where cyclists specifically train for increased anaerobic power, it may be the preferred time to incorporate plyometric training.

4. Sample size

The sample size was not only limited (13 in the experimental group and seven in the control group), but the groups also consisted of road cyclists and mountain bikers. Although the results show that there were no differences in any of the outcome variables between the road cyclists and the mountain bikers at the baseline, it is possible that the road cyclists may not have responded favourably to the plyometric

training program. Due to the small numbers in each group, it could not be established for certain whether the cyclists responded differently to the program. Another confounding variable was the large age range of the subjects in the study (18 to 40 years). It is possible that the older cyclists might have responded differently to plyometric training than the younger cyclists, which might have resulted in different training effects. Most of the studies in the literature have been done on relatively young subjects, and therefore it is not known whether one can expect similar responses from young and old individuals to plyometric training programs.

5. Outcome variables

5.1 Vertical jump test

The vertical jump test that was performed can be used to determine whether the subjects' vertical jumping power increased after the plyometric program, and therefore increased the subject's leg power. The vertical jump test did not show a strong correlation with the peak power output during the 30-second Wingate test ($r = 0.23$) or the outdoor time trials' time ($r = 0.08$). Therefore, this test might not have been specific enough in predicting peak power output in cycling.

The vertical jump test has also shown to have contradictory results when used to measure changes in response to a plyometric training program, though most studies have found an improvement (Matavulj *et al.*, 2001; Hammett and Hey, 2003; Luebbers *et al.*, 2003; Malisoux *et al.*, 2005; Markovic, 2007), some studies found no statistically significant improvements (Turner *et al.*, 2003; Chimera *et al.*, 2004), similar to the results in this study. It is therefore possible that the vertical jump test is not sensitive enough to depict small improvements in leg power.

Luebbers *et al.* (2003) found an initial decline in vertical jumping height directly after their plyometric training program, after which vertical jump performance was statistically significantly improved after four weeks. Martel *et al.* (2005) also found

further improvements in vertical jumping height four weeks after finishing their plyometric training program. Most studies have tested their subjects only directly after the intervention period, similarly to this study. However, perhaps the main effects of plyometric training are only evident after a few weeks. It is therefore possible that this may also be the same in this study.

5.2 Bench pull test

The bench pull test was used to determine upper body strength (shoulder and arm pulling strength), and measure any improvements in upper body strength after the plyometric training program. The bench pull test showed a strong correlation with both the indoor time trial ($r = 0.99$) and outdoor time trial time ($r = 0.72$). These results suggest that the bench pull test might be a good predictor of upper body strength in mountain bikers. The strong correlation with the indoor time trial, were probably just accidental, because the cyclists' bike were fixed to the Kingcycle while performing the time trial, and therefore upper body strength does not really have an influence on the indoor time trial performance.

5.3 Laboratory cycling tests

The incremental test to exhaustion performed on a cycle ergometer, have on numerous occasions shown to be an effective manner to predict cycling performance, more specifically aerobic capacity (VO_{2max}). To measure whether plyometric training would improve the endurance capacities of a cyclist, there is no better test than performing a VO_{2max} test.

The 30-second Wingate test is used to determine short-term cycling performance, measuring average power output and peak power output. Because the plyometric exercises during the intervention program was performed to improve the power in cyclists, this test was ideal to measure any improvements in power on an ergometer.

The five-kilometer time trial performed on the Kingcycle, is an ideal way to simulate an outdoor time trial, removing most factors that might influence a cyclists' performance. The short distance might not have given a true reflection of the cyclists' time trialing ability, but if the test was too long, the idea of testing the power of the cyclist over a short distance would have been lost.

5.4 Outdoor time trial

The 4.4-kilometer outdoor time trial might have been too short a distance to show the effect of plyometric exercise on mountain biking performance. The reasoning behind the short distance is to measure whether power over a short distance would improve. In a recent study done by Prins *et al.* (2007), an eight-kilometer circuit was cycled four times to measure outdoor time trial performance. The longer the distance, the more other type of variables (endurance) start to play a role and influence the performance.

E. Conclusion

The findings of this study suggest that plyometric training have limited effects on the performance of cyclists. However, this study was the first attempt to investigate this particular question. It is proposed that the content and timing of the plyometric training program, as well as some of the outcome variables be revised in future studies. At this point, the possibility that plyometric exercise can have a positive effect on the performance of cyclists, cannot be excluded in its entirety.

REFERENCES

1. ARCHER, L. (2004). "Plyometrics training." *Fredys Fitness Zone*. 29 August. [<http://www.fredysnet.com/id15.html>]. 31 August 2007.
2. BARON, R. (2001). Aerobic and anaerobic power characteristics of off-road cyclists. *Medicine and Science in Sports and Exercise*, 33(8):1387-1393.
3. BASSETT, D.R. AND HOWLEY, E.T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise*, 32(1):70-84.
4. BASTIAANS, J.J., VAN DIEMEN, A.B.J.P., VENEBERG, T. AND JEUKENDRUP, A.E. (2001). The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. *European Journal of Applied Physiology*, 86(1):79-84.
5. BEHM, D.G. (1995). Neuromuscular implications and applications of resistance training. *Journal of Strength and Conditioning Research*, 9(4):264-274.
6. BENDER, C. (2002). "Plyometrics." *Weights Net*. 18 May 1995. [<http://www.weightsnet.com/Docs/plyometrics.html#what>]. 8 July 2007.
7. BENTLEY, D.J., WILSON, G.J., DAVIE, A.J. AND ZHOU, S. (1998). Correlation between peak power output, muscular strength and cycle time trial performance in triathletes. *Journal of Sports Medicine and Physical Fitness*. 38(3):201-207.
8. BISHOP, D. AND JENKINS, D.G. (1996). The influence of resistance training on the critical power function and time to fatigue at critical power. *Australian Journal of Science and Medicine in Sport*, 28(4):101-105.

9. BISHOP, D. JENKINS, D.G. AND MACKINNON, L.T. (1998). The relationship between plasma lactate parameters, W_{peak} and 1-h cycling performance in woman. *Medicine and Science in Sports and Exercise*, 30:1270-1275.
10. BISHOP, D., JENKINS, D.G., MACKINNON, L.T., MCENIERY, M. AND CAREY, M.F. (1999). The effects of strength training on endurance performance and muscle characteristics. *Medicine and Science in Sports Exercise*, 31(6):886-891.
11. BLIMKIE, C.J.R., RICE, S., WEBBER, C.E., MARTIN, J., LEVY, D. AND GORDON, C.L. (1996). Effects of resistance training on BMC and density in adolescent females. *Canadian Journal of Physiology and Pharmacology*, 74(9):1025-1033.
12. BOMPA, T.O. (1999). *Periodization: theory and methodology of training*, 4th Edition. Illinois: Human Kinetics, pp.27-52.
13. BOYLE, M. (2004). *Functional training for sports*. Human Kinetics, pp.85-126.
14. BRANDON, L.J. (1995). Physiological factors associated with middle distance running performance. *Sports Medicine*, 19(4):268-277.
15. BURKE, E.B. (1983). Improved cycling performance through strength training. *Journal of the National Strength and Conditioning Association*, 5(3):6-7, 70-71.
16. BURKE, E.R. (1986). *Science of cycling*. Illinois: Human Kinetics, pp.1-20.
17. BURKE, E.R. (1995). *Serious Cycling*. University of Colorado: Human Kinetics, pp.1-22, 37-55, 68-78, 105-132.

18. CABLE, N.T. (1990). Cardiovascular function. In: R.G. ESTON AND T. REILLY (Eds). *Kinanthropometry and Exercise Physiology Laboratory Manual: Tests, Procedures and Data: Exercise Physiology*, Volume 2. London: Routledge, pp.117-133.
19. CHIMERA, N.J., SWANIK, K.A., SWANIK, C.B. AND STRAUB, S.J. (2004). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of Athletic Training*, 39(1):24-31.
20. CHU, D.A. (1998). *Jumping into plyometrics*, 2nd Edition. Illinois: Human Kinetics, pp.1-8, 27-67.
21. COETZEE, B. (2007). 'n Literatuuroorsig van pliometrie as 'n oefeningstegniek. *South African Journal for Research in Sport, Physical Education and Recreation*, 29(1):61-82.
22. CONLEY, D., KRAHENBUHL, G. AND BURKETT, L. (1981). Training for aerobic capacity and running economy. *Physician and Sportsmedicine*, 9:107-115.
23. CONLEY, D., KRAHENBUHL, G., BURKETT, L. AND MILLAR, A. (1984). Following Steve Scott: physiological changes accompanying training. *Physician and Sportsmedicine*, 12:103-106.
24. COSTILL, D.L., FLYNN, M.G., KIRMAN, J.P., HOUMARD, J.A., MITCHELL, J.B., THOMAS, R. AND HAN PARK, S. (1988). Effects of repeated days of intensified training on muscle glycogen and swimming performance. *Medicine and Science of Sports and Exercise*, 20(3): 249-254.

25. COSTILL, D.L., THOMPSON, H. AND ROBERTS, E.L. (1973). Fractional utilization of aerobic capacity during distance running. *Medicine and Science in Sports and Exercise*, 5(4):248-253.
26. COYLE, E.F., COGGAN, A.R., HOPPER, M.K. AND WALTERS, T.J. (1988). Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology*, 64(6):2622-2630.
27. COYLE, E.F., FELTNER, M.E. AND KAUTZ, S.A. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine and Science in Sports and Exercise*, 23:93-107.
28. COYLE, E.F., MARTIN, W.H., EHSANI, A.A., HAGBERG, J.M., BLOOMFIELD, S.A., SINACORE, D.R. AND HOLLOSZY, J.O. (1983). Blood lactate threshold in some well-trained ischemic heart disease patients. *Journal of Applied Physiology*, 54(1):18-23.
29. CRAIG, N.P. AND NORTON, K.I. (2001). Characteristics of track cycling. *Sports Medicine*, 31(7):457-468.
30. CUNNINGHAM, D., MCCRIMMON, D. AND VLACH, L (1979). Cardiovascular response to interval and continues training in woman. *European Journal of Applied Physiology*, 41(3):187-197.
31. DANIELS, J. (1998). *Daniels' running formula*. Human Kinetics: Champaign Ill.
32. DAVISON, R.C., SWAN, D., COLEMAN, D. AND BIRD, S. (2000). Correlates of simulated hill climb performance. *Journal of Sports Sciences*, 18(2):105-110.

33. DOCHERTY, D. AND SPORER, B. (2000). A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. *Sports Medicine*, 30(6):385-394.
34. EBBEN, W.P. (2002). Complex training: A brief review. *Journal of Sports Science and Medicine*, 1:42-46.
35. FARIA, E.W., PARKER, D.L. AND FARIA, I.E. (2005). The science of cycling: Physiology and training – Part 1. *Sports Medicine*, 35(4):285-312.
36. FARIA, I.E., FARIA, E.W., ROBERTS, S. AND YOSHIMURA, D. (1989). Comparison of physical and physiological characteristics in elite young and mature cyclists. *Research Quarterly for Exercise and Sport*, 60(4):388-395.
37. FERNANDEZ-GARCIA, B., PEREZ-LANDALUCE, J., RODRIGUEZ-ALONSO, M. AND TERRADOS, N. (2000). Intensity of exercise during road race pro-cycling competition. *Medicine and Exercise in Sports and Exercise*, 32(5):1002-1006.
38. FITTS, R.H., MCDONALD, K.S. AND SCHLUTER, J.M. (1991). The determinants of skeletal muscle force and power: their adaptability with changes in activity pattern. *Journal of Biomechanics*, 24(1):11-12.
39. FLETCHER, I.M. AND HARTWELL, M. (2004). Effect of an 8-week combined weights and plyometrics training program on golf drive performance. *Journal of Strength and Conditioning Research*, 18(1):59-62.
40. FOSS, M.L. AND KETEYIAN, S.J. (1998). *Physiological basis for exercise and sport*, 6th Edition. McGraw-Hill International Editions, pp.181-184.

41. GRAVELLE, B.L. AND BLESSING, D.L. (2000). Physiological adaptation in woman concurrently training for strength and endurance. *Journal of Strength and Conditioning Research*, 14(1):5-13.
42. GREGOR, R.J. AND CONCONI, F. (2000). Road cycling. *Handbook of Sports Medicine and Science*. UK: Blackwell Science Ltd, pp.1-17, 46-53.
43. GREGOR, R.J. (2000). Biomechanics of cycling. In: GARRET, W.E. AND KIRKENDALL, D.T. (Eds). *Exercise and Sport Science*. Philadelphia (PA): Lippincott Williams and Williams, pp.515-537.
44. GREIWE, J.S., HICKNER, R.C., HANSEN, P.A., RACETTE, S.B., CHEN, M.M. AND HOLLOSZY, J.O. (1999). Effects of endurance exercise training on muscle glycogen accumulation in humans. *Journal of Applied Physiology*, 87(1):222-226.
45. GUYTON, A.E. and HALL, J.E. (2000). *The textbook of medical physiology*, 5th Edition. Philadelphia, PA: W.B. Saunders.
46. HAGBERG, J.M. AND COYLE, E.F. (1983). Physiological determinants of endurance performance as studied in competitive walkers. *Medicine and Science in Sports and Exercise*, 15(4):287-289.
47. HÄKKINEN, K. (1989). Neuromuscular and hormonal adaptations during strength and power training. *Journal of Sports Medicine and Physical Fitness*, 29(1):9-26.
48. HAKKINEN, K. (1994). Neuromuscular adaptation during strength training, aging, detraining, and immobilization. *Critical Reviews in Physical and Rehabilitation Medicine*, 6:161-198.

49. HAKKINEN, K., KOMI, P.V. AND ALEN, M. (1985). Effects of explosive type strength training on isometric force and relaxation time, electromyographic and muscle fiber characteristics of leg extensor muscles. *Acta Physiologica Scandinavica*, 125(4):587-600.
50. HAKKINEN, K., PAKARINEN, A., KYRÖLÄINEN, H., CHENG, S., KIM, D.H. AND KOMI, P.V. (1990). Neuromuscular adaptations and serum hormones in females during prolonged power training. *International Journal of Sports Medicine*, 11(2):91-98.
51. HAMEL, P., SIMONEAU, J.A., LORTIE, G., BOULAY, M.R. AND BOUCHARD, C. (1986). Heredity and muscle adaptation to endurance training. *Medicine and Science in Sports and Exercise*, 18(6):690-696.
52. HAMILTON, R.J., PATON, C.D. AND HOPKINS, W.G. (2006). Effect of high-intensity resistance training on performance of competitive distance runners. *International Journal of Sports Physiology and Performance*, 1:40-49.
53. HAMMETT, J.B. AND HEY, W.T. (2003). Neuromuscular adaptation to short-term (4 weeks) ballistic training in trained high school athletes. *Journal of Strength and Conditioning Research*, 17(3):556-560.
54. HARMER, A.R, MCKENNA, M.J., SUTTON, J.R., SNOW, R.J., RUELL, P.A., BOOTH, J., THOMPSON, M.W., MACKAY, N.A., STATHIS, C.G., CRAMERI, R.M., CAREY, M.F. AND EAGER, D.M. (2000). Skeletal muscle metabolic and ionic adaptations during intense exercise following sprint training in humans. *Journal of Applied Physiology*, 89(5):1793-1803.
55. HAWLEY, J.A. AND BURKE, L.M. (1998). Peak performance: training and nutritional strategies for sport. Sydney: Allen and Unwin.

56. HAWLEY, J.A. AND HOPKINS, W.G. (1995). Aerobic glycolytic and aerobic lipolytic power systems: a new paradigm with implications for endurance and ultraendurance training. *Sports Medicine*, 19:240-250.
57. HAWLEY, J.A. AND NOAKES, T.D. (1992). Peak power output predicts maximal oxygen uptake and performance in trained cyclists. *European Journal of Applied Physiology*, 65(1):79-83.
58. HEIDERSCHEIT, B., PALMER-MCLEAN, K. AND DAVIES, G. (1996). The effects of isokinetic vs. plyometric training on the shoulder internal rotators. *Journal of Orthopedic and Sports Physical Therapy*, 23(2):125-133.
59. HENNESSY, L.C. AND WATSON, A.W.S. (1994). The interference effects of training for strength and endurance simultaneously. *Journal of Strength and Conditioning Research*, 8(1):12-19.
60. HICKSON, R.C., DVORAK, B.A., GOROSTIAGA, E.M., KUROWSKI, T.T. AND FOSTER, C. (1988). Potential for strength and endurance training to amplify endurance performance. *Journal of Applied Physiology*, 65(5):2285-2290.
61. HICKSON, R.C., ROSENKOETTER, M.A. AND BROWN, M.M. (1980). Strength training effects on aerobic power and short-term endurance. *Medicine and Science of Sports and Exercise*, 12(5):336-339.
62. HILL, A.V. (1970). *First and Last Experiments in Muscle Mechanics*. Cambridge: Cambridge University Press.
63. HOFF, J., GRAN, A. AND HELGERUD, J. (2002a). Maximal strength training improves aerobic endurance performance. *Scandinavian Journal of Medicine and Science in Sports*, 12(5):288-295.

64. HOFF, J., HELGERUD, J. AND WISLØFF, U. (2002b). Endurance training into the next millennium; muscular strength training effects on aerobic endurance performance: a review. *American Journal of Medicine and Sports*, 4(1):58-67.
65. HOLLOSZY, J. (1975). Adaptation of skeletal muscle to endurance exercise. *Medicine and Science in Sports Exercise*, 7:155-164.
66. KRAEMER, W.J. (2000). Endocrine responses to resistance exercise. In: BAECHLE, T.R. AND EARLE, R.W. (Eds). *Essentials of strength training and conditioning*, 2nd Edition. Human Kinetics. pp.91-114.
67. HOROWITZ, J.F., SIDOSSIS, L.S. AND COYLE, E.F. (1994). High efficiency of type I muscle fibers improves performance. *International Journal of Sports Medicine*, 15(3):152-157.
68. HUMAN, E., POHL, K., ROBERTS, T. AND VAN VELDEN, D. (1990). *Go cycling: a South African manual*. Cape Town: Tafelberg Publishers Ltd, pp.81-88.
69. HURLEY, B.F., SEALS, D.R., EHSANI, A.A., CARTIER, L.-J., DALSKY, G.P., HAGBERG, J.M. AND HOLLOSZY, J.O. (1984). Effects of high intensity strength training on cardiovascular function. *Medicine and Science in Sports Exercise*, 16(5):483-488.
70. HUTCHINSON, M.R., TREMAIN, L., CHRISTIANSEN, J. AND BEITZEL, J. (1998). Improving leaping ability in elite rhythmic gymnasts. *Medicine and Science in Sports and Exercise*, 30(10):1543-1547.
71. IMPELLIZZERI, F.M. AND MARCORA, S.M. (2007). The physiology of mountain biking. *Sports Medicine*, 37(1):59-71.

72. IMPELLIZZERI, F.M., RAMPININI, E., SASSI, A, MOGNONI, P. AND MARCORA, S. (2005b). Physiological correlates to off-road cycling performance. *Journal of Sports Science*, 23:41-47.
73. IMPELLIZZERI, F.M., MARCORA, S.M., RAMPININI, E., MOGNONI, P. AND SASSI, A. (2005a). Correlations between physiological variables and performance in high level cross country off road cyclists. *British Journal of Sports Medicine*, 39(10):747-751.
74. IMPELLIZZERI, F., SASSI, A., RODRIGUEZ-ALONSO, M., MOGNONI, P. AND MARCORA, S. (2002). Exercise intensity during off-road cycling competitions. *Medicine and Science in Sports and Exercise*, 34(11):1808-1813.
75. IZQUIERDO, M., HÄKKINEN, K., IBÁÑEZ, J., KRAEMER, W.J. AND GOROSTIAGA, E.M. (2005). Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men. *European Journal of Applied Physiology*, 94(1-2):70-75.
76. JANSSEN, P. (2001). *Lactate threshold training*. USA: Human Kinetics, pp. 1-14.
77. JEUKENDRUP, A.E., CRAIG, N. AND HAWLEY, J. (2000). Physiological demands of world class cycling. *Journal of Science and Medicine in Sport*, 3(4):400-419.
78. JONES, A.M. AND CARTER, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine*, 29(6):373-386.

79. JUNG, A.P. (2003). The impact of resistance training on distance running performance. *Sports Medicine*, 33(7):539-552.
80. KOHRT, W.M., BLOOMFIELD, S.A., LITTLE, K.D., NELSON, M.E. AND YINGLING, V.R. (2004). Physical activity and bone health. *The American College of Sports Medicine*, 36(11):1985-1996.
81. KOMI, P.V. (2003). Stretch Shortening Cycle. In: P.V. KOMI AND THE INTERNATIONAL FEDERATION OF SPORTS MEDICINE & IOC MEDICAL COMMISSION (Eds). *Strength and power in sport*, 2nd Edition. Melbourne, Australia: Blackwell Scientific Publications, pp:184-202.
82. KUBACHKA, E.M. AND STEVENS, W.C. (1996). *The Effects of Plyometric Training and Strength Training on the Musculature Capacities of the Trunk*. Williams & Wilkins, 28(5):192.
83. KUBUKELI, Z.N., NOAKES, T.D. AND DENNIS, S.C. (2002). Training techniques to improve endurance exercise performances. *Sports Medicine*, 32(8):489-509.
84. KUIPERS, H., VERSTAPPEN, F.T.J., KEIZER, H.A. AND GUERTEN, P. (1985). Variability of aerobic performance in the laboratory and its physiological correlates. *International Journal of Sports Medicine*, 6:197-201.
85. KYRÖLÄINEN, H., AVELA, J., MCBRIDE, J.M., KOSKINEN, S., ANDERSEN, J.L., SIPILÄ, S., TAKALA, T.E.S. AND KOMI, P.V. (2005). Effects of power training on muscle structure and neuromuscular performance. *Scandinavian Journal of Medicine and Science in Sports*, 15(1):58-64.

86. LAKE, M.J. AND CAVANAGH, P.R. (1996). Six weeks of training does not change running mechanics or improve running economy. *Medicine and Science of Sports and Exercise*, 28(7):860-869.
87. LAURSEN, P.B. AND JENKINS, D.G. (2002). The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance cyclists. *Sports Medicine*, 32(1):53-73.
88. LAURSEN, P.B. AND RHODES, E.C. (2001). Factors affecting performance in an ultraendurance triathlon. *Sports Medicine*, 31(3):195-209.
89. LAURSEN, P.B., SHING, C.M., PEAKE, J.M., COOMBES, J.S. AND JENKINS, D.G. (2002). Interval training program optimization in highly trained endurance cyclists. *Medicine and Science in Sports Exercise*, 34(11):1801-1807.
90. LEE, H., MARTIN, D.T., ANSON, J.M., GRUNDY, D. AND HAHN, A.G. (2002). Physiological characteristics of successful mountain bikers and professional road cyclists. *Journal of Sports Sciences*, 20(12):1001-1008.
91. LEVERITT, M., ABERNETHY, P.J., BARRY, B.K. AND LOGAN, P.A. (1999). Concurrent strength and endurance training: a review. *Sports Medicine*, 28(6):413-427.
92. LINDSAY, F.H., HAWLEY, J.A., MYBURGH, K.H., SCHOMER, H.H., NOAKES, T.D. AND DENNIS, S.C. (1996). Improved athletic performance in highly trained cyclists after interval training. *Medicine and Science in Sports Exercise*, 28(11):1427-1434.

93. LONDEREE, B.R. (1986). The use of laboratory test results with long distance runners. *Sports Medicine*, 3(3):201-213.
94. LONDEREE, B.R. (1997). Effect of training on lactate/ventilatory thresholds: a meta analysis. *Medicine and Science in Sports and Exercise*, 29(6):837-843.
95. LUCIA, A., HOYOS, J. AND CHICHARRO, J.L. (2000a). Physiological response to professional road cycling: climbers vs time trialists. *International Journal of Sports Medicine*, 21:505-512.
96. LUCIA, A., HOYOS, J. AND CHICHARRO, J.L. (2000b). Preferred pedaling cadence in professional cycling. *Medicine and Science in Sports and Exercise*, 33(8):1361-1366.
97. LUCIA, A., HOYOS, J. AND CHICHARRO, J.L. (2001). Physiology of professional road cycling. *Sports Medicine*, 31(5):325-337.
98. LUCIA, A., HOYOS, J., SANTALLA, A. (2002). Kinetics of VO₂ in professional cyclists. *Medicine and Science in Sports and Exercise*, 34:320-325.
99. LUCIA, A., PARDO, J., DURANTEZ, A., HOYOS, J. AND CHICHARRO, J.L. (1998). Physiological differences between professional and elite road cyclists. *International Journal of Sports Medicine*, 19:342-348.
100. LUCIA, L., HOYOS, J., CARJAVAL, A. AND CHICHARRO, J.L. (1999). Heart rate response to professional road cycling: the Tour de France. *International Journal of Sports Medicine*, 20(3): 167-172.

101. LUEBBERS, P.E., POTTEIGER, J.A., JULVER, M.W., THYFAULT, J.P., CARPER, M.J. AND LOCKWOOD, R.H. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal of Strength and Conditioning Research*, 17(3):704-709.
102. MACDOUGALL, J.D., HICKS, A.L., MACDONALD, J.R., MCKELVIE, R.S., GREEN, H.J. AND SMITH, K.M. (1998). Muscle performance and enzymatic adaptations to sprint interval training. *Journal of Applied Physiology*, 84(6):2138-2142.
103. MACRAE, H-H., HISE, K.J. AND ALLEN, P.J. (2000). Effects of front and dual suspension mountain bike systems on uphill cycling performance. *Medicine and Science in Sports and Exercise*, 32(7):1276-1280.
104. MALISOUX, L., FRANCAUX, M., NIELENS, H. AND THEISEN, D. (2006a). Stretch-shortening cycle exercises: an effective training paradigm to enhance power output of human single muscle fibers. *Journal of Applied Physiology*, 100:771-779.
105. MALISOUX, L., FRANCAUX, M., NIELENS, H., RENARD, P., LEBACQ, J. AND THEISEN, D. (2006b). Calcium sensitivity of human single muscle fibers following plyometric training. *Medicine and Science in Sports and Exercise*. 38(11):1091-1098.
106. MALISOUX, L., MARC, F. AND THEISEN, D. (2005). Effect of plyometric training on mechanical properties of human single muscle fibers. *The American College of Sports Medicine*. 37(5):288.

107. MARCINIK, E.J., POTTS, J., SCHLABACH, G., WILL, S., DAWSON, P. AND HURLEY, B.F. (1991). Effects of strength training on lactate threshold and endurance performance. *Medicine and Science in Sports Exercise*, 23(6):739-743.
108. MARKOVIC, G. (2007). Does plyometric training improve vertical jump height? a meta analytical review. *British Journal of Sports Medicine*, 41:349-355.
109. MARTEL, G.F., HARMER, M.L., LOGAN, J.M. AND PARKER, C.B. (2005). Aquatic plyometric training increases vertical jump in female volleyball players. *The American College of Sports Medicine*, 37(10):1814-1819.
110. MATAVULJ, D., KUKOLJ, M., UGARKOVIC, D., TIHANYI, J. AND JARIC, S. (2001). Effects of plyometric training on jumping performance in junior basketball players. *Journal of Sports Medicine and Physical Fitness*, 41(2):159-164.
111. MATHEWS, C.K. AND VAN HOLDE, K.E. (1990). *Biochemistry*. The Benjamin/Cummings Publishing Company: CA, pp. 1035-1074.
112. MCARDLE, W.D., KATCH, F.I. AND KATCH, V.L. (2001). *Exercise physiology: energy, nutrition, and human performance* (5th ed). Lippincott Williams & Wilkins, pp. 525-526, 358-382.
113. MCCOLE, S.D., CLANEY, K., CONTE, J.C., ANDERSON, R. AND HAGBERG, J.M. (1990). Energy expenditure during bicycling. *Journal of Applied Physiology*, 68(2):748-753.

114. MCNAUGHTON, L.R., ROBERTS, S. AND BENTLEY, D.J. (2006). The relationship among peak power output, lactate threshold, and short-distance cycling performance: effects of incremental exercise test design. *Journal of Strength and Conditioning Research*, 20(1):157-161.
115. MILLER, M.G., BERRY, D.C., BULLARD, S. AND GILDERS, R. (2002). Comparisons of land-based and aquatic-based plyometric programs during an 8-week training period. *Journal of Sport Rehabilitation*, 11(4):268-283.
116. MORGAN, D.W., MARTIN, P.E. AND KRAHENBUHL, G.S. (1989). Factors affecting running economy. *Sports Medicine*, 7(5):310-330.
117. MUJIKA, I. AND PADILLA, S. (2001). Physiological and performance characteristics of male professional road cyclists. *Sports Medicine*, 31(7):479-487.
118. NEUMANN, G in SHEPHARD, R.J. AND ASTRAND, P. -O. (1992). Endurance in sport. *The Encyclopedia of Sports Medicine*, Oxford: Blackwell Scientific Publications.
119. NEVILL, A.M., RAMSBOTTOM, R. AND WILLIAMS, C. (1992). Scaling physiological measurements for individuals of different body size. *European Journal of Applied Physiology and Occupational Physiology*, 65(2):110-117.
120. NEVILL, M.E., BOOBIS, L.H., BROOKS, S.T. AND WILLIAMS, C. (1989). Effect of training on muscle metabolism during treadmill sprinting. *Journal of Applied Physiology*, 67(6):2376-2382.
121. NICOL, C., AVELA, J. AND KOMI, P.V. (2006). The stretch-shortening cycle: a model to study naturally occurring neuromuscular fatigue. *Sports Medicine*, 36(11):977-999.

122. NOAKES, T. (1991). *Lore of running*. Leisure Press: Champaign Ill.
123. NORRIS, S.R. AND PETERSEN, S.R. (1998). Effects of endurance training on transient oxygen uptake responses in cyclists. *Journal of Sport Sciences*, 16(8):733-738.
124. O'BRYANT, H.S., BYRD, R. AND STONE, M.H. (1988). Cycle ergometer performance and maximum leg and hip strength adaptations to two different methods of weight training. *Journal of Applied Sport Science Research*, 2(2):27-30.
125. PAAVOLAINEN, L., HAKKINEN, K., HAMALAINEN, I., NUMMELA, A. AND RUSKO, H. (1999). Explosive-strength training improves 5-km running time by improving running economy and muscle power. *Journal of Applied Physiology*, 86(5):1527-1533.
126. PADILLA, S., MUJICA, I., CUESTA, G. AND GOIRIENA, J.J. (1999). Level ground and uphill cycling ability in professional cycling. *Medicine and Science in Sports and Exercise*, 31(6):878-885.
127. PADILLA, S., MUJICA, I., CUESTA, G., POLO, J.S. AND CHATARD, J.-C. (1996). Validity of a velodrome test for competitive road cyclists. *European Journal of Applied Physiology*, 73(5):446-451.
128. PADILLA, S., MUJICA, I., ORBANANOS, J. AND ANGULO, F. (2000). Exercise intensity during competition time trials in professional road cycling. *Medicine and Science in Sports and Exercise*, 32(4):850-856.

129. PADILLA, S., MUJICA, I., ORBANANOS, J., SANTISTEBAN, J., ANGULO, F. AND GOIRIENA, J.J. (2001). Exercise intensity and load during mass-start stage races in professional road cycling. *Medicine and Science in Sports and Exercise*, 33(5):796-802.
130. PALMER, G.S., NOAKES, T.D. AND HAWLEY, J.A. (1999). Metabolic and performance responses to constant-load vs variable-intensity exercise in trained cyclists. *Journal of Applied Physiology*, 87(3):1186-1196.
131. PATON, C.D. AND HOPKINS, W.G. (2004). Effects of high-intensity training on performance and physiology of endurance athletes. *Sportscience*, 8:25-40.
132. PATON, C.D. AND HOPKINS, W.G. (2005). Combining explosive and high-resistance training improves performance in competitive cyclists. *Journal of Strength Training and Conditioning Research*, 19(4):826-830.
133. PETTITT, R. (1999). The role of plyometrics in the scope of periodized training model. *Journal of Performance Enhancement*, 1(1):11-20.
134. POTACH, D.H. AND CHU, D.A. (2000). Plyometric training. In T.R BAECHLE AND R.W. EARLE (Eds), *Essentials of strength training and conditioning*, Human Kinetics: Champaign IL, pp.426-470.
135. POTTEIGER, J.A., LOCKWOOD, R.H., HAUB, M.D., DOLEZAL, B.A., ALMUZAINI, K.S., SCHROEDER, J.M. AND ZEBAS, C.J. (1999). Muscle power and fiber characteristics following 8 weeks of plyometric training. *Journal of Strength and Conditioning Research*, 13(3):275-279.
136. PRENTICE, W.E. (2003). *Arnheim's principles of athletic training: a competency-based approach*, 11th Edition. New York: McGraw-Hill.

137. PRINS, L., TERBLANCHE, E. AND MYBURGH, K.H. (2007). Field and laboratory correlates of performance in competitive cross-country mountain bikers. *Journal of Sports Sciences*, 25(8):927-935.
138. RADCLIFFE, J.C. AND FARENTINOS, R.C. (1999). *High-powered plyometrics*. Human Kinetics: Champaign IL.
139. RIMMER, E. AND SLEIVERT, G. (2000). Effects of a plyometrics intervention program on sprint performance. *Journal of Strength and Conditioning Research*, 14(3):295-301.
140. ROBINSON, L.E., DEVOR, S.T., MERRICK, M.A. AND BUCKWORTH, J. (2004). The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women. *Journal of Strength and Conditioning Research*, 18(1):84-91.
141. SALE, D.G. (1991). Neural adaptation to strength training. In: KOMI, P.V. (Eds). *Strength and power in sports. The Encyclopedia of Sports Medicine*. Oxford, UK: Blackwell, pp.249-265.
142. SALE, D.G. (1987). Influence of exercise and training on motor unit activation. *Exercise and Sport Sciences Reviews*, 15:95-151.
143. SALLET, P., MATHIEU, R., FENECH, G. AND BAVEREL, G. (2006). Physiological differences of elite and professional road cyclists related to competition level and rider specialization. *Journal of Sports Medicine and Physical Fitness*, 46(3):361-365.
144. SALTIN, B. (1990). Anaerobic capacity: past, present and prospective. In: TAYLOR, A.W., GOLLINCK, P.D., GREEN, H.J. *et al.* (Eds). *Biochemistry of exercise VII*. Human Kinetics: Champaign IL, pp.387-413.

145. SAUNDERS, P.U., PYNE, D.B., TELFORD, R.D., PELTOLA, E.M., CUNNINGHAM, R.B. AND HAWLEY, J.A. (2004). Nine weeks of plyometric training improves running economy in highly trained distance runners. *The American College of Sports Medicine*. 36(5):254.
146. SCHULTE-EDELMANN, J.A., DAVIES, G.J., KERNOZEK, T.W. AND GERBERDING, E.D. (2005). The effects of plyometric training of the posterior shoulder and elbow. *Journal of Strength and Conditioning Research*, 19(1):129-134.
147. SIFF, M (2000). *Facts and Fallacies of Fitness*, 4th Edition. Denver: USA.
148. SIFF, M. AND VERKHOSHANSKY, Y.V. (1999). *Supertraining*, 4th Edition. Denver: USA.
149. SJODIN, B. AND JACOBS, I. (1981). Onset of blood lactate accumulation and marathon running performance. *International Journal of Sports Medicine*, 2(1):23-26.
150. SJODIN, B. AND SVEDENHAG, J. (1985). Applied physiology of marathon running. *Sports Medicine*, 2(2):83-99.
151. SPURRS, R.W., MURPHY, A.J. AND WATSFORD, M.L. (2003). The effect of plyometric training on distance running performance. *European Journal of Applied Physiology*, 89(1):1-7.
152. STAPELFELDT, B., SCHWIRTZ, A., SCHUMACHER, Y.O. AND HILLEBRECHT, M. (2004). Workload demands in mountain bike racing. *International Journal of Sports Medicine*, 25(4):294-300.

153. STEGMANN, H. AND KINDERMANN, W. (1982). Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 mmol/l-1 lactate. *International Journal of Sports Medicine*, 3(2):105-110.
154. STEPTO, N.K., HAWLEY, J.A., DENNIS, S.C. AND HOPKINS, W.G. (1999). Effects of different interval-training programs on cycling time-trial performance. *Medicine and Science in Sports and Exercise*, 31 (5):736-741.
155. STONE, M.H., SANDS, W.A., CARLOCK, J., CALLAN, S., DICKIE, D., DAIGLE, K., COTTON, J., SMITH, S.L. AND HARTMAN, M. (2004). The importance of isometric maximum strength and peak rate-of-force development in sprint cycling. *Journal of Strength and Conditioning Research*, 18(4):878-884.
156. SWAIN, D.P., COAST, J.R., CLIFFORD, P.S., MILLIKEN, M.C. AND STRAY-GUNDERSEN, J. (1987). Influence of body size on oxygen consumption during bicycling. *Journal of Applied Physiology*, 62:668-672.
157. TABATA, I., NISHIMURA, K., KOUZAKI, M., HIRAI, Y., OGITA, F., MIYACHI, M. AND YAMAMOTO, K. (1997). Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic and VO_{2max} . *Medicine and Science in Sports and Exercise*, 28(10):1327-1330.
158. TANAKA, H. AND SWENSEN, T. (1998). Impact of resistance training on endurance performance: a new form of cross-training? *Sports Medicine*, 25(3):191-200.
159. TAYLOR-MASON, A.M. (2005). High-resistance interval training improves 40-km time-trial performance in competitive cyclists. *Sportscience*, 9:27-31.

160. TESCH, P.A. (1988). Skeletal muscle adaptations consequent to long-term heavy resistance exercise. *Medicine and Science in Sports and Exercise*, 20 (5):132-134.
161. THODEN, J. (1991). Testing aerobic power. In: MACDOUGALL, J. WENGER, H. AND GREEN, H. (Eds). *Physiological testing for the high-performance athlete*, 2nd Edition. Human Kinetics: Champaign (IL), pp.107-173.
162. TURNER, A.M., OWINGS, M. AND SCHWANE, J.A. (2003). Improvement in running economy after 6 weeks of plyometric training. *Journal of Strength and Conditioning Research*, 17(1):60- 67.
163. VOIGHT, M. AND TIPPETT, S. (2001). Plyometric exercise in rehabilitation. In: PRENTICE, W.E. AND VOIGHT, M.I. (Eds). *Techniques in Musculoskeletal Rehabilitation*. USA: McGraw-Hill Companies, pp:167-178.
164. VOSSEN, J.F., KRAMER, J.F., BURKE, D.G. AND VOSSEN, D.P. (2000). Comparison of dynamic push-up training and plyometric push-up training on upper-body power and strength. *Journal of Strength and Conditioning Research*, 14(3): 248-253.
165. WARNER, S.E., SHAW, J.M. AND DALSKY, G.P. (2002). Bone mineral density of competitive male mountain and road cyclists. *Bone*, 30(1):281-286.
166. WESTGARTH-TAYLOR, C., HAWLEY, J.A., RICKARD, S., MYBURGH, K.H., NOAKES, T.D. AND DENNIS, S.C. (1997). Metabolic and performance adaptations to interval training in endurance-trained cyclists. *European Journal of Applied Physiology*, 75(4):298-304.

167. WESTON, A.R., MYBURGH, K.H., LINDSAY, F.H., DENNIS, S.C., NOAKES, T.D. AND HAWLEY, J.A. (1997). Skeletal muscle buffering capacity and endurance performance after high-intensity training by well-trained cyclists. *European Journal of Applied Physiology*, 75(1):7-13.
168. WIDRICK, J.J., STELZER, J.E., SHOEPE, T.C. AND GARNER, D.P. (2002). Functional properties of human muscle fibers after short-term resistance training. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology*, 283(2):408-416.
169. WILK, K. AND VOIGHT, M. (1994). Plyometrics for the shoulder complex. In: ANDREWS, J., WILK, K. (Eds). *The Athlete's shoulder*. New York: Churchill Livingstone, pp.543-565.
170. WILK, K., VOIGHT, M., KEIRNS M., GAMBETTA, V., ANDRES, J. AND DILLMAN, C. (1993). Stretch-shortening drills for the upper extremities: Theory and clinical application. *Journal of Orthopedic and Sports Physical Therapy*, 17(5):225-239.
171. WILKERSON, G.B., COLSTON, M.A., SHORT, N.I., NEAL, K.L., HOEWISCHER, P.E. AND PIXLEY, J.J. (2004). Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *Journal of Athletic Training* 39(1):17-23.
172. WILSON, G.J., MURPHY, A.J. AND PRYOR, J.F. (1994). Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. *Journal of Applied Physiology*, 76(6):2714-2719.

173. WINGO, J.E., CASA, D.J., BERGER, E.M., DELLIS, W.O., KNIGHT, J.C. AND MCCLUNG, J.M. (2004). Influence of pre-exercise glycerol hydration beverage on performance and physiologic function during mountain-bike races in the heat. *Journal of Athletic Training*, 39(2):169-175.
174. WITZKE, K.A. AND SNOW, C.M. (2000). Effects of plyometric jump training on bone mass in adolescent girls. *American College of Sports Medicine*, 32(6):1051-1057.
175. YOUNG, W. (1991). Plyometrics for Netball. *Sports Coach*, October-December: 26-28.
176. YOUNG, W.B. (2006). Transfer of strength and power training to sports performance. *International Journal of Sports Physiology and Performance*, 1:74-83.
177. ZAPPE, D.H. AND BAUER, T. (1989). Planning off- and preseason training for road cycling. *National Strength and Conditioning Association Journal*, 11(2):35-39.

APPENDIX A

INGELIGDE TOESTEMMING

Titel van navorsingsprojek:

Die effek van pliometriese oefeninge op die prestasie van fietsryers.

Verwysingsnommer: _____

Verklaring deur toetspersoon:

Ek, die ondergetekende , _____
[ID: _____], van (adres) _____
_____.

bevestig dat:

1. Ek uitgenooi is om deel te neem aan bogenoemde navorsingsprojek wat deur die Departement Sportwetenskap aan die Universiteit van Stellenbosch onderneem word.
2. Daar aan my verduidelik is dat:
 - 2.1 die doel van die projek is om te toets of pliometriese oefeninge die prestasie van fietsryers sal verbeter.
 - 2.2 ek 11 toetse sal aflê:
 - 2.2.1 Liggaamslengte, liggaamsmassa, soepelheid en vetpersentasie gemeet sal word.
 - 2.2.2 Die krag in my arms en bene met standaard fiksheidstoetse gemeet sal word.
 - 2.2.3 'n VO_{2maks} toets of 'n fietsergometer om my uithouvermoë kapasiteit te toets.
 - 2.2.4 'n Vyf kilometer tydtoets op 'n kingcycle sal aflê in die kortste moontlike tyd.
 - 2.2.5 'n 30 sekonde toets op die fietsergometer om my maksimale kraguitset te bepaal.
 - 2.2.6 'n Uitdagende vyf kilometer bergfietsroete by Coetzenburg in die kortste moontlike tyd moet voltooi.
 - 2.3 Indien ek vir die oefengroep gekies word, ek 'n oefenprogram vir 14 weke onder die toesig van die navorsers sal moet volg. Daar word vereis dat ek minstens 3 oefensessies per week by die Departement Sportwetenskap

bywoon. Die minimum oefentyd sal 30 minute per sessie wees en die maksimum tyd sal 60 minute per sessie wees.

- 2.4 Al die toetse na 14 weke herhaal sal word.
- 2.5 Geen indringende prosedures (bv. bloedtrek, inspuitings) of middels toegedien sal word nie. Bloedlaktaatvlakke sal tydens die submaksimale toetse m.b.v. 'n vingerprik gemeet word (ongeveer 5 monsters per toets).
3. Ek gewaarsku is dat daar 'n moontlikheid bestaan dat ek een of meer simptome tydens die oefentoetse mag ondervind. Dit sluit in duiseligheid, naarheid, abnormale hoë bloeddruk, abnormale hartklop, of 'n toegetrekte (benoude) bors. Ek verstaan dat ek enige tyd die oefentoetse mag staak wanneer ek enige van hierdie simptome ondervind.
4. Ek meegedeel is dat die inligting wat ingewin word as vertroulik behandel sal word, maar dat die bevindinge wel in vaktydskrifte gepubliseer kan word.
5. Die navorsers/toetsafnemers en/of die Universiteit van Stellenbosch nie verantwoordelik gehou kan word vir enige besering wat ek moontlik kan opdoen gedurende enige van die toetse ingesluit in die projek nie.
6. Die inligting wat hierbo weergegee is, deur _____ aan my in Engels/Afrikaans verduidelik is. Ek is ook die geleentheid gegee om vrae te vra en al my vrae is bevredigend beantwoord.
7. Daar is aan my verduidelik dat my deelname vrywillig is en dat ek enige tyd aan die projek mag onttrek.
8. Ek is meegedeel dat daar geen koste aan my deelname verbonde is nie.

Ek neem die verantwoordelikheid om 'n uiterste poging aan te wend om al die toetse te voltooi.

Ek besef dat die uitkoms van elke toets afhang van hoe goed ek gemotiveerd is om my beste te gee.

Ek neem die verantwoordelikheid om **hoogs gemotiveerd** deel te neem aan hierdie projek en elke toets tot die beste van my vermoë af te lê.

Ek stem hiermee vrywillig in om aan bogemelde projek deel te neem.

Geteken te _____ op _____ 20_____

Toetspersoon

Getuie

VERKLARING DEUR NAVORSER

Ek, _____, verklaar dat ek:

1. die inligting vervat in hierdie dokument aan _____ verduidelik het;
2. Haar/hom versoek het om vrae aan my te stel indien daar enigiets onduidelik was;
3. Dat hierdie gesprek in Afrikaans/Engels plaasgevind het.

Geteken te _____ op _____ 20_____

Navorsers

Getuie

INFORMED CONSENT

Title of research project:

The effect of plyometric exercises on the performance of cyclists.

Reference number: _____

Consent of Subject:

I, _____ [ID: _____]
from (address) _____
_____.

confirm that:

1. I was invited to participate in the above-mentioned project conducted by the Department of Sport Science of the University of Stellenbosch.
2. It was explained to me that:
 - 2.1 The aim of this project is to determine whether plyometric exercises can improve the performance of cyclists.
 - 2.2 I will participate in 11 tests:
 - 2.2.1 Body length, mass, flexibility and fat percentage will be measured.
 - 2.2.2 The power in my arms and legs will be measured with standard fitness tests.
 - 2.2.3 A VO_{2max} test on a cycle ergometer that will test my endurance capacity.
 - 2.2.4 A five-kilometre time trial must be completed on a kingcycle in the shortest possible time.
 - 2.2.5 A 30 second test on a cycle ergometer that will determine my maximum power output.
 - 2.2.6 A challenging five-kilometre mountain biking route at Coetzenburg must be completed in the shortest possible time.
 - 2.3 If I am selected for the training group, I must follow an exercise program for 14 weeks under the supervision of the researchers. I will be required to attend at least 3 exercise sessions per week at the Department of Sport Science. The minimum training time will be 30 minutes per session and the maximum time will be 60 minutes per session.
 - 2.4 All the tests will be repeated 14 weeks after the first evaluation.

- 2.5 I have to finish a challenging five-kilometer mountain biking route in shortest possible time. The route will test my cycling power to maximal.
3. I am warned that I might develop one or more symptoms during the exercise tests. This include nausea, dizziness, high or low blood pressure, heart beat disorders (too slow, too rapid, or irregular), shortness of breath or bronchoconstriction. I understand that I can stop the exercise tests at any time when I experience one of these symptoms.
4. I was informed that the information obtained during this study will be held confidential, but the findings may be published in a journal.
5. The researcher/ test administrators and/or the University of Stellenbosch can not be held responsible for any injury that might occur during the test or exercises in the study.
6. The above mentioned information was explained to me by _____ in English/Afrikaans. I was also given the opportunity to ask questions, and all my questions were answered satisfactorily.
7. It was explained to me that my participation is voluntarily and that I can withdraw from the project at any time.
8. I was informed that there are no costs linked to my participation.

I take responsibility to try my best to finish all tests in the study.

I realise that the result of each test will depend on how much I am motivated to do my best.

I take responsibility to be **highly motivated** while participating in the study, and to finish each test to the best of my ability.

With this I volunteer to participate in the above-mentioned project.

Signed at _____ on _____ 20_____

Subject

Witness

Statement of the Researcher

I, _____ declare that I:

1. Explained the information contained in this document to _____
2. Requested the subject to ask questions if anything was unclear.
3. Performed this conversation in English/Afrikaans.

Signed at _____ on _____ 20 _____

Researcher

Witness

APPENDIX B

Daily Questionnaire

General

Date:.....

Waking Heart Rate:.....

Body Weight:.....

Feeling: Tired

OK

Good

Injuries/Sickness:.....

.....

Today's Training Session

Weather: Cold

Excellent

Cool

Warm

Windy

| Total Distance | | Total Duration | |
|-----------------------|-------------|----------------|------------|
| Type | Speed | | Heart Rate |
| Mountain Bike: | Min: | Min: | |
| Road: | Ave: | Ave: | |
| | Max: | Max: | |

Comments:.....

.....

No training - why not?.....

.....

Competition:

Results:.....

.....

APPENDIX C

GYMNASIUM TRAINING PROGRAM

1st Session

Warm-up on bike for 5 min at low intensity

Cardio-circuit

Stretches for 10 min

2nd Session

Warm-up on bike for 5 min at low intensity

Core: 4 Bridges (Front, left side, back, right side) 30 s each
Squirm 3 sets of 20 reps

Strength: Backward lunge with Rotation - 3 sets of 12 on each leg
Pull Ups - 2 sets to max
Dips - 2 sets to max
Hip Extension - 3 sets of 12 (6 on each leg)
Single leg Squats - 3 sets of 12 (6 on each leg)

Stretches for 10 min

3rd Session

Warm-up on bike for 5 min at low intensity

Core: Straight leg Raises 3 sets of 20

Cardio circuit

Stretches for 10 min

4th Session

Warm-up on bike for 5 min at low intensity

Core: 4 Bridges (Front, left side, back, right side) 30 s each

Cardio circuit

Stretches for 10 min

5th Session

Warm-up on bike for 5 min at low intensity

Core: 4 Bridges (Front, left side, back, right side) 40 s each
Bridge with alternate leg raise 3 sets of 12
Squirm 3 sets of 20

Strength: Hip Extensions - 3 sets of 12 reps on each leg
Step-ups - 3 sets of 12 reps on each leg

Stretches for 10 min

6th Session

Warm-up on bike for 5 min at low intensity

Core: Bridge - 2 sets of 40s (front and back)
Bridge - 2 sets of 10 lifts (sides)
Ab Slide - 3 sets of 20 reps

Cardio circuit

Stretches for 10 min

7th Session

Core: Bridge - 2 sets of 40s (front and back)
Bridge - 2 sets of 10 lifts (sides)
Superman - 2 sets of 20 reps

Cardio circuit

Stretches for 10 min

8th Session

Warm-up on bike for 5 min at low intensity

| | | | |
|-----------|------------------------------|---|--------------------------------|
| Core: | Bridge | - | 2 sets of 40s (front and back) |
| | Bridge | - | 2 sets of 10 lifts (sides) |
| | Pike Hold | - | 2 sets of 10 reps |
| Strength: | Dumbbell lunge with rotation | - | 3 sets of 12 reps |
| | 3 way lunge with rotation | - | 3 sets of 12 reps |
| | Pull-ups | - | 2 sets overarm, 1 set underarm |
| | Dips | - | 2 sets to max |
| | 1 Legged squad | - | 2 sets of 12 on each leg |

Stretches for 10 min

9th Session

Warm-up on bike for 5 min at low intensity

| | | | |
|----------|--------------------|---|--------------------------------|
| Core: | Bridge | - | 2 sets of 40s (front and back) |
| | Bridge | - | 2 sets of 10 lifts (sides) |
| | Reverse Crunch | - | 2 sets of 10 reps |
| Balance: | Balance on one leg | - | 20s per leg |

Cardio Circuit

Stretches for 10 min

10th Session

Warm-up on bike for 5 min at low intensity

| | | |
|-------|--|-------------------|
| Core: | 4 Bridges (Front, left side, back, right side) | 40s each |
| | Leg Throws | 2 sets of 20 reps |

Cardio Circuit

Stretches for 10 min

APPENDIX D**PLYOMETRIC TRAINING PROGRAM****Week 1****Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|--------------------------|-------------|-------------|----------------|--------------------|
| Skips: Forward | 4 | 5 | | |
| Backward | 4 | 5 | | |
| Double Leg Vertical Jump | 2 | 10 | 2,2,2,2,2 | |
| 2-Foot Ankle Hop | 2 | 10 | 2,2,2,2,2 | |
| Chest Pass | 3 | 10 | | 1 |
| 2-Hand Overhead Throw | 2 | 10 | | 1 |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|--------------------------|-------------|-------------|----------------|--------------------|
| Power Skips | 4 | 5 | | |
| Double Leg Vertical Jump | 4 | 5 | 1,2,2 | |
| Jump & Reach | 4 | 5 | 1,2,2 | |
| Squat Jumps | 4 | 5 | 1,2,2 | |
| Sit-ups | 2 | 10 | | 1 |
| Pullover Throws | 2 | 15 | | 1 |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|-------------------------|-------------|-------------|----------------|--------------------|
| Skips: Forward | 2 | 5 | | |
| Backward | 2 | 5 | | |
| 2-Foot Ankle Hop | 2 | 10 | 2,2,2,2,2 | |
| Single-leg Push-off | 2 | 2*10 | | |
| Lateral Push-off | 2 | 2*10 | | |
| One Step Wall Throws | 3 | 10 | | |
| 2-Hand Side-Side Throws | 2 | 10 | alternating | |

Week 2**Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|---------------------------|------|------|---------------------|-------------|
| Power Skips | 4 | 5 | | |
| Double Leg Vertical Jumps | 4 | 5 | 1,2,2 | |
| Double Leg Tuck Jumps | 2 | 10 | 1,1,1,1,1,1,1,1,1,1 | |
| Squat Jumps | 4 | 5 | 1,2,2 | |
| Chest Pass | 3 | 10 | | 1 |
| 2-Hand Overhead Throw | 2 | 10 | | 1 |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------|------|------|-----------|-------------|
| Jump to Box | 2 | 10 | | |
| Jump & Reach | 4 | 5 | 1,2,2 | |
| 2-Foot Ankle Hop | 2 | 10 | 2,2,2,2,2 | |
| Alternate Leg Push-off | 2 | 10 | | |
| Sit-ups | 2 | 10 | | 1 |
| Pullover Throws | 2 | 15 | | 1 |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|-------------------------|------|------|-------------|-------------|
| Skips: Forward | 2 | 5 | | |
| Backward | 2 | 5 | | |
| Squat Jumps | 4 | 5 | 2,3 | |
| Single-leg Push-off | 2 | 2*10 | | |
| Lateral Push-off | 2 | 2*10 | | |
| One Step Wall Throws | 3 | 10 | | |
| 2-Hand Side-Side Throws | 2 | 10 | alternating | |

Week 3**Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|---------------------------------|-------------|-------------|-----------------|--------------------|
| Power Skips | 2 | 6 | | |
| Double Leg Tuck Jumps | 3 | 8 | 1,1,1,1,1,1,1,1 | |
| Double Leg Hops | 3 | 6 | | |
| Jump Over Barrier | 3 | 6 | | |
| Single Arm Alternate Leg Bounds | 4 | 8 | | |
| Single Arm Throws | 2 | 2*10 | | 1 |
| Side Throws | 2 | 12 | alternating | 1 |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|--------------------------|-------------|-------------|----------------|--------------------|
| Front Barrier Hops | 2 | 8 | | |
| 2-Foot Ankle Hops | 2 | 10 | 3,3,4 | |
| Cyclic Split Squat Jumps | 4 | 6 | | |
| Jump from Box | 2 | 10 | | |
| Side-Side Push-off | 2 | 10 | | |
| Depth Push-up | | 10-8-6 | | |
| Pullover Throws | 2 | 15 | | 2 |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|---------------------------------|-------------|-------------|----------------|--------------------|
| Double Leg Vertical Jumps | 2 | 5 | 2,3 | |
| Lateral Barrier Hops | 2 | 2*8 | | |
| Squat Box Jumps | 3 | 8 | | |
| Lateral Box Jumps | 2 | 2*4 | | |
| Double Arm Alternate Leg Bounds | 4 | 8 | | |
| Shot Put | 2 | 2*10 | | 2 |
| Sit-ups | 2 | 10 | | 2 |

Week 4

Rest between sets & exercises: 2min

Warm-up: Jogging for 2 * 20m at 50% pace

Session 1

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|--------------------------|------|------|-------------|-------------|
| Double Leg Tuck Jumps | 3 | 10 | 2,2,2,2,2 | |
| Double Leg Hops | 3 | 8 | | |
| Jump Over Barrier | 3 | 8 | | |
| Cyclic Split Squat Jumps | 4 | 8 | | |
| Single Arm Throws | 2 | 2*10 | | |
| Side Throws | 2 | 12 | alternating | 2 |
| Pullover Throws | 2 | 15 | | 2 |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|-----------------------|------|--------|---------|-------------|
| Front Barrier Hops | 3 | 8 | | |
| Lateral Barrier Hops | 2 | 2*8 | | |
| Jump from Box | 2 | 10 | | |
| Side-Side Push-off | 2 | 10 | | |
| Single Arm Leg Bounds | 4 | 8 | | |
| Depth Push-up | | 10-8-6 | | |
| Sit-ups | 2 | 10 | | 2 |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|---------------------------------|------|------|-----------------|-------------|
| Double Leg Butt Kicks | 2 | 8 | 1,1,1,1,1,1,1,1 | |
| Cyclic Split Squat Jumps | 6 | 6 | | |
| Squat Box Jumps | 3 | 10 | | |
| Lateral Box Jumps | 3 | 2*3 | | |
| Double Arm Alternate Leg Bounds | 4 | 8 | | |
| Shot Put | 2 | 2*10 | | 2 |
| Single Arm Throws | 2 | 2*10 | | 2 |

Week 5**Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|-----------------------|------|--------|-------------|-------------|
| Power Skips | 2 | 6 | | |
| Double Leg Tuck Jumps | 3 | 10 | 2,2,2,2,2 | |
| Double Leg Hops | 3 | 8 | | |
| Jump Over Barrier | 3 | 8 | | |
| Lateral Barrier Hops | 2 | 2*8 | | |
| Depth Push-ups | | 10-8-6 | | |
| Side Throws | 3 | 8 | alternating | 2 |
| Pullover Throws | 2 | 15 | | 2 |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|-----------------------|------|------|---------|-------------|
| Double Leg Butt Kicks | 3 | 8 | 2,2,2,2 | |
| Single Arm Leg Bounds | 4 | 10 | | |
| Front Barrier Hops | 3 | 8 | | |
| Side-Side Push-off | 3 | 8 | | |
| Jump From Box | 2 | 10 | | |
| Single Arm Throws | 2 | 2*10 | | 2 |
| Sit-ups | 2 | 15 | | 2 |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|---------------------------------|------|--------|---------|-------------|
| Skips: Forward | 2 | 6 | | |
| Backward | 2 | 6 | | |
| Double Arm Alternate Leg Bounds | 4 | 10 | | |
| Cyclic Split Squat Jumps | 6 | 8 | | |
| Squat Box Jumps | 3 | 10 | | |
| Lateral Box Jumps | 2 | 2*4 | | |
| Depth Push-ups | | 10-8-6 | | |
| Shot Put | 2 | 2*10 | | 2 |

Week 6**Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------|------|---------|-----------------|-------------|
| Double Leg Tuck Jumps | 4 | 6 | 3,3 | |
| Double Leg Zigzag Hops | 3 | 10 | | |
| Pike Jumps | 3 | 8 | 1,1,1,1,1,1,1,1 | |
| Single Leg Hops | 4 | 2*6 | | |
| Squat Throws | 3 | 8 | | |
| Depth Push-ups | | 12-10-8 | | |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------------------|------|------|-----------------|-------------|
| Double Leg Butt Kicks | 3 | 8 | 4,4 | |
| Squat Depth Jumps | 4 | 6 | | |
| Single Leg Vertical Jumps | 4 | 2*6 | 1,1,1,1,1,1,1,1 | |
| Box Drill with Rings | 3 | 12 | | |
| Depth Jump with Standing Long Jump | 4 | 5 | | |
| Power Drops | 2 | 10 | | |
| Sit-ups | 2 | 20 | | |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|----------------------------------|------|------|---------|-------------|
| Split Squat Jumps | 3 | 8 | | |
| Depth Jumps | 3 | 8 | | |
| Depth Jump with Lateral Movement | 2 | 10 | | |
| Single Leg Depth Jump | 3 | 6 | | |
| Ricochests | 3 | 10 | | |
| Squat Jump Throws | 2 | 8 | | |
| Shot Put | 2 | 2*12 | | |

Week 7**Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------|-------------|-------------|----------------|--------------------|
| Double Leg Zigzag Hops | 3 | 10 | | |
| Pike Jumps | 3 | 8 | | |
| Single Leg Hops | 2 | 2*8 | | |
| Single Leg Tuck Jumps | 4 | 2*6 | 2,2,2 | |
| Squat Throws | 3 | 8 | | |
| Depth Push-ups | | 12-10-8 | | |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------------------|-------------|-------------|----------------|--------------------|
| Squat Depth Jumps | 4 | 6 | | |
| Single Leg Vertical Jumps | 2 | 2*8 | 2,2,2,2 | |
| Box Drill with Rings | 3 | 12 | | |
| Depth Jump to Second Box | 3 | 8 | | |
| Depth Jump with Standing Long Jump | 4 | 6 | | |
| Power Drops | 2 | 10 | | |
| Sit-ups | 2 | 20 | | |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|----------------------------------|-------------|-------------|-----------------|--------------------|
| Split Squad Jumps | 3 | 8 | | |
| Single Leg Butt Kicks | 2 | 2*8 | 1,1,1,1,1,1,1,1 | |
| Depth Jump with Lateral Movement | 2 | 10 | | |
| Single Leg Depth Jump | 4 | 2*6 | | |
| Ricochests | 3 | 10 | | |
| Squad Jump Throws | 2 | 10 | | |
| Shot Put | 2 | 2*12 | | |

Week 8**Rest between sets & exercises: 2min****Warm-up: Jogging for 2 * 20m at 50% pace****Session 1**

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------|-------------|-------------|----------------|--------------------|
| Double Leg Zigzag Hops | 3 | 10 | | |
| Pike Jumps | 3 | 10 | | |
| Single Leg Hops | 4 | 2*8 | | |
| Single Leg Tuck Jumps | 4 | 2*8 | 2,2,2,2 | |
| Squat Throws | 2 | 10 | | |
| Depth Push-ups | | 12-10-8 | | |

Session 2

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|------------------------------------|-------------|-------------|----------------|--------------------|
| Squat Depth Jumps | 3 | 8 | | |
| Single Leg Vertical Jumps | 3 | 10 | 3,3,4 | |
| Box Drill with Rings | 3 | 12 | | |
| Depth Jump to Second Box | 3 | 8 | | |
| Depth Jump with Standing Long Jump | 4 | 6 | | |
| Power Drops | 2 | 12 | | |
| Sit-ups | 2 | 20 | | |

Session 3

| Exercise | Sets | Reps | Pattern | Weight (kg) |
|----------------------------------|-------------|-------------|----------------|--------------------|
| Split Squat Jumps | 3 | 8 | | |
| Single Leg Butt Kicks | 2 | 2*8 | 2,2,2,2 | |
| Depth Jump with Lateral Movement | 2 | 12 | | |
| Single Leg Depth Jump | 2 | 2*6 | | |
| Ricochests | 3 | 10 | | |
| Squat Jump Throws | 2 | 10 | | |
| Shot Put | 2 | 2*12 | | |