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## The effect of strength training on 3km performance in recreational female endurance runners

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**THE EFFECT OF STRENGTH TRAINING ON 3KM  
PERFORMANCE IN RECREATIONAL FEMALE ENDURANCE  
RUNNERS**

**By**

**Cherina Michelle Rice**

**A thesis submitted in partial fulfillment of the requirements for the award of**

**Master of Science (Sports Science)**

**School of Biomedical and Sports Science, Edith Cowan University**

**Date of Submission:**

**April 2004**

## USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

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I certify that this thesis does not, to the best of my knowledge and belief:

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\_\_\_\_\_

Date 15/11/04\_\_\_\_\_

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Now...let the next chapter begin!

## ABSTRACT

The purpose of this study was to investigate whether a strength training program, as an additive to endurance training, would cause significant improvements in 3km run time in a group of recreational female endurance runners when compared to endurance training only. Subjects were 16 active women, randomly assigned to either a running only group (control group, n=9) or a combined strength and endurance training group (experimental group, n=7). The ten-week training program for both groups consisted of an endurance running program three times per week, which included steady-state endurance running, tempo runs and interval training. The experimental group however, participated in additional strength training with heavy loads (up to five repetition maximum). Subjects were tested pre- and post-training in a 3km time trial,  $\dot{V}O_{2\text{ peak}}$ , running economy, muscular strength (1RM), as well as body composition and girth. A one-way ANCOVA, with the pre-training values as the covariate, was used to analyse the data. Both training groups showed a non-significant improvement in 3km performance times after the respective training programs. However, it was found that the experimental group times were not significantly different ( $p>0.05$ ) to the control group post training. There was a trend ( $p=0.08$ ) evident in the experimental group's time which improved  $106.7 \pm 91.4$  seconds, while the control group improved  $77.3 \pm 93.0$  seconds. The combined strength and endurance training group showed a significant increase ( $p<0.05$ ) in lower body strength for the parallel squat (6% increase) and hamstring curl (45.1% increase) and a strong trend ( $p=0.06$ ) for an increase in upper body strength for the bench press (11.9% increase). No significant strength changes were found for the control group. There were no significant differences evident in either group for  $\dot{V}O_{2\text{ peak}}$ , running economy, body composition or girth measurements. This study found a non-significant trend for improvement in 3km times when low repetition strength training was added to a running program. The main reason for the trend in improvement in the experimental group seemed to be the increased lower limb strength levels, which may improve variables such as increased stride length. It is concluded that combined strength and endurance training may improve running performance and its inclusion is recommended in the training programs of recreational athletes.

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## **GLOSSARY OF ABBREVIATIONS**

|            |  |
|------------|--|
| <b>BPM</b> | <b>Beats per Minute</b>                |
| <b>CSE</b> | <b>Combined Strength and Endurance</b> |
| <b>HR</b>  | <b>Heart Rate</b>                      |
| <b>1RM</b> | <b>One Repetition Maximum</b>          |
| <b>RE</b>  | <b>Running Economy</b>                 |
| <b>RER</b> | <b>Respiratory Exchange Rate</b>       |
| <b>SD</b>  | <b>Standard Deviation</b>              |
| <b>TEM</b> | <b>Technical Error of Measurement</b>  |
| <b>WA</b>  | <b>Western Australia</b>               |

## **CHAPTER ONE**

### **1.0 INTRODUCTION**

#### **1.1 Background to the Study**

Traditionally, endurance runners have performed little or no strength training in order to improve their level of performance. The most common argument against combining strength and endurance training is that skeletal muscle cannot adapt to both of these types of training either metabolically or morphologically (Leveritt, Abernethy, Barry, & Logan, 1999). Strength training has been shown to increase muscle hypertrophy and motor unit recruitment but decrease capillary density and mitochondrial volume and consequently has been thought to be counter productive to endurance training (Sale, Jacobs, Macdougall, & Garner, 1990). Conversely, endurance training has been found to decrease strength and muscle fibre size (McCarthy, Pozniak, & Agre, 2002; Sale et al., 1990).

In contrast, many researchers have stated that a properly structured training program may increase the effectiveness of the entire training plan (Getmanets & Travin, 1989). In a review by Henrikson and Tesch (1999) the authors stated that a strength training program should be a prerequisite for endurance training, as strength training improves neuromuscular function and may also assist in injury prevention. Furthermore, they stated that the neuromuscular system has a large capacity to adapt to a combination of training stimuli.

Endurance athletes tend to be more ectomorphic when compared to athletes in other popular sports, and this has previously led to an avoidance of strength training exercises in order to maintain a low body mass. It has also been believed that muscular strength is not a high priority due to the fact that the majority of an endurance athlete's workload relies heavily upon muscular endurance and that only a minimal amount of muscle strength is

required for endurance events (L. Burke, 1998). However, some scientists have refuted this by stating that although endurance running requires that an athlete maintain a high aerobic power over a long period of time, the athlete must also maintain a high velocity during the race (Paavolainen, Nummela, & Rusko, 1999b). Running velocity is the product of stride length and stride rate. Recent research has shown that the difference between faster and slower runners was that faster runners were capable of generating a greater amount of ground reaction force (thus increasing stride length) than the slower runners, not by how rapidly the limbs were repositioned in the air (stride rate) (Weyand, Sternlight, Bellizzi, & Wright, 2000).

While past research has been sceptical, if not completely opposed to combined strength and endurance training, a new generation of endurance runners is finding increased support for this method of training. Recently however, it is thought that strength training is important to endurance performance via two mechanisms. Firstly, strength training induces an increase in muscle action potential amplitude, the efficiency of the neuromuscular system and the muscle's ability to generate force. This, results in an improved ability of the body to cope with a submaximal load (Behm & St. Pierre, 1998). Secondly, strength training may improve running economy, lactate threshold, muscular power, and improved neuromuscular characteristics (Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999a).

Ideally, endurance runners desire the benefit of strength training as discussed above, however, hypertrophy of muscle is to be avoided. Therefore, strength and conditioning methods that influence the neuromuscular system and minimise muscle hypertrophy, such as heavy strength training (1-5 repetitions / set), maximum power training (30-60% 1 RM) and plyometrics may be worthy of consideration (Tesch, 1987).

A study by Paavolainen et al. (1999a) used explosive-strength training in order to improve elite male cross country runner's running economy and 5 km performance times. Explosive-strength training included various short sprints and jumping exercises (e.g.

alternate and bilateral counter-movement jumps, drop jumps, hurdle hops). After nine weeks of training, the endurance athletes that performed this type of training, showed an improvement in running economy and their 5-km timed run when compared to a control group. The results of this study lend credibility to the idea that endurance performance can be enhanced by the athlete's ability to increase muscle power production. However, the method of explosive-strength training employed in the Paavolainen and co-workers study was used on elite runners who were already at a high level of training.

When selecting the method of strength development to be used in training, an athlete's current fitness and conditioning level must be carefully considered. Olympic lifts and maximum power training both require a sound strength base, with Olympic lifts also requiring a level of technical proficiency (Allerheiligen, 1994). Plyometric exercises such as box jumps and bounding can be hazardous, due to the high impact forces generated and is generally not recommended for athletes inexperienced with strength training (Allerheiligen, 1994). Therefore, general strength training should be used as the logical first step in the development of inexperienced athletes.

## **1.2 Purpose of the Study**

This study will use recreational female endurance runners to investigate the effects of a strength training program on endurance performance. This method of strength training should ideally not induce muscular hypertrophy. Plyometric strength training and Olympic lifts require a mastery of technique that is not appropriate for beginners. Furthermore, maximal power output methods typically rely on a sound strength base. A strength training program, which incorporates low repetitions with heavy loads (1-5 repetitions), is the most appropriate for the purpose of this study. Therefore, the aim of this study is to investigate whether incorporating such strength training exercises into an endurance runner's training program will result in improvements of performance in a 3km time trial when compared to runners using endurance training alone.



### **1.3 Significance of the Study**

The majority of prior investigation into concurrent strength and endurance training has been focused upon the effect of endurance on strength levels (Hennessy & Watson, 1994; Hickson, 1980; Leveritt et al., 1999). However, what little research has been conducted into studying the results of endurance running performance when combined with a strength training program has yielded positive results (Hickson, Dvorak, Gorostiaga, Kurowski, & Foster, 1988; Paavolainen, Hakkinen, & Rusko, 1991; Paavolainen et al., 1999b). These studies have attributed improved running performance to an improvement in running economy. Even fewer studies examine what is perhaps the most important variable in determining the success of concurrent strength and endurance training, that being race time. To this investigator's knowledge, there have been no previous investigations which have examined the effect of strength training on a runner's 3km performance race times. Results will be applicable to a population of recreational endurance runners, as well as providing beneficial training information for the athletic coaches.

### **1.4 Research Questions**

- i) Will a strength training program, as an additive to endurance training, cause significant improvements in 3km performance in a group of recreational female endurance runners?
- ii) Will an improvement in running economy be a contributing factor to improvements seen in performance times?

### **1.5 Hypothesis**

- i) There will be a significant improvement in 3km running times in a group of runners using maximal strength training as an additive to their running training, when compared to runners who will train solely through a running program.
- ii) There will be a significant pre-post test improvement in running economy in a group performing combined strength and endurance training.

## **1.6 Limitations and Delimitations of the Study**

### **1.6.1 Limitations**

- The subjects of the study have varying fitness levels, but are mostly considered “recreational”.
- Testing and weather conditions for the 3km timed run will have to be matched as closely as possible.
- Subjects may have to miss a training session for various unpredictable reasons. For example: doctors appointments, work, etc. A training log will be kept and subjects will be made aware of the importance of training program adherence.

### **1.6.2 Delimitations**

- The subjects selected must run the 3km timed run in less than 20 minutes in order to participate in the study. The two groups will be equally matched for ability levels in attempt to make the training groups as homogeneous as possible.
- The subjects selected will not have participated in a weight training program in the three months prior to the study.
- The subjects must be females, between the ages of 17-27 years old.
- Training times will be flexible, with alternate workout times available for those who may miss a session.

## **1.7 Definition of Selected Terms**

- i. 1 RM: One repetition maximum. The maximum amount of weight that a person can lift in one attempt.
- ii. Fartlek Training: Swedish for 'speed play', it involves alternating fast and slow running over natural terrains. It is a form of interval training.
- iii. Force: That which changes or tends to change the state of rest or motion in matter. A muscle generates force in a muscle action.

- iv. **Interval Training:** a system of physical conditioning in which the body is subjected to short but regularly repeated periods of work stress interspersed with adequate periods of relief.
- v. **Maximal Oxygen Consumption ( $\dot{V}O_{2max}$ ):** The highest rate of oxygen consumption attainable during maximal or exhaustive exercise, representing aerobic power. One of the best predictors of cardiorespiratory endurance capacity.
- vi. **Motor Unit:** An individual motor nerve and all the muscle fibres it innervates.
- vii. **Muscular Endurance:** The ability of a muscle or muscle group to perform repeated contractions against a light load for an extended period of time.
- viii. **Muscular Strength:** The force or tension that a muscle, or group of muscles, can exert against a resistance in one maximal effort.
- ix. **Neuromuscular Adaptations:** Adaptive changes of the nervous system in response to training.
- x. **Power:** The product of an applied force and the velocity with which it is applied.
- xi. **Respiratory Exchange Ratio (RER):** The ratio of carbon dioxide released to the oxygen consumed during nutrient metabolism. It reflects the type of substrates being used as an energy source.
- xii. **Running Economy:** The aerobic demand at a given sub maximal running speed.
- xiii. **Repetition Running:** Similar to interval training but differs in the length of the work interval and the level of recovery between repetitions. Also intensity of each repetition is kept constant.
- xiv. **Submaximal Oxygen Consumption ( $\dot{V}O_2$ ):** Oxygen consumption at rest or submaximal levels of exercise.
- xv. **Specificity of Training:** Principal underlying construction of a training program for a specific activity or skill and the primary energy systems involved in performance. Training is dynamically similar to the muscle contractions that are required in the competitive event.

## **CHAPTER TWO**

### **2.0 REVIEW OF LITERATURE**

#### **2.1 Introduction**

The following review of literature will address topics specifically pertaining to this study. The first section will discuss past and present views on the effects of concurrent strength and endurance training. The next two sections will discuss neural adaptations and muscular hypertrophy associated with combined strength and endurance (CSE) training. Next, specificity of training will be discussed. Finally, there will be a discussion on running economy, followed by a summary.

#### **2.2 Concurrent Strength and Endurance (CSE) Training**

There has been extended debate amongst researchers, as to whether concurrent strength and endurance (CSE) training is an additive or a deterrent to athletic performance. Past research has demonstrated that there is clearly a lack of agreement as to whether CSE training negatively affects the development of one component or the other (Hennessy & Watson, 1994). It has been suggested that an “interference effect”, in which the two types of training methods work against each other, occurs as a result of CSE training. It is evident that development of strength may be compromised when endurance training is performed simultaneously with high-resistance training (Bell, Petersen, Wessel, Bagnall, & Quinney, 1991). This “interference effect” is thought to hinder optimal strength and endurance gains when compared to either training in isolation (Hennessy & Watson, 1994).

Debate regarding whether or not CSE training is beneficial or detrimental to an athlete's performance stems from conflicting evidence at the biological level. Sale et al. (1990)

stated that strength training was detrimental to performance gains in endurance due to the apparent decrease in both capillary and mitochondrial volume density. In agreement, Tesch (1988) concluded that in addition to the hypertrophic effect, both mitochondrial volume density and capillary density were reduced following long-term heavy resistance training. Similarly, the activity of enzymes reflecting the aerobic energy system decreased, hindering the aerobic endurance capacity. These findings lend credibility to an endurance athlete's fear of developing too much muscle, and it would explain the desire of endurance athletes to be "toned" as opposed to "bulky". For this reason, maintaining a relatively small cross sectional area of muscle is of great importance to the endurance athlete.

Although the above studies showed an inhibited effect on hypertrophy, they did not investigate the effect that strength training had on endurance performance, which is the focus of the present research study. A study more relevant to endurance performance by Sale et al. (1990) acknowledged this "interference effect" but expanded on the topic stating that, on the other hand, a combination of some forms of strength and endurance training may in fact be 'additive' rather than antagonistic. The authors further refuted any interference of strength training on endurance performance by stating that some strength training programs have increased both short and long-term endurance and also produced small but significant increases in maximal oxygen uptake  $\dot{V}O_{2max}$ . Table 1 outlines research pertaining to CSE training. From examining Table 1, it becomes apparent that many of these studies have focused upon training regimens in which strength development was the dominant goal, unlike an endurance athlete's training regimen, which would focus primarily on endurance training. Furthermore, the study by Paavolainen et al. (1999a) was the only one that investigated the effects on actual race performance time.

### **2.3 Neural Adaptations to CSE Training**

Critics of CSE training contend that skeletal muscle cannot adapt metabolically or morphologically to both strength and endurance training simultaneously, and that this incompatibility occurs because many of the adaptations at the muscle level occurring in response to strength training are opposite from those observed after endurance training

**Table 1**

*Past Research Investigating Concurrent Strength and Endurance Training*

| Researcher  | Subjects                            | Strength Training                                       | Exercises  | Results / Notes  |
|---|-------------------------------------|---|--|--|
| (Bell et al., 1991)                                   | 31 male Rowers                      | Low Velocity Resistance<br>8-12 reps                    | knee extension / flexion, hip extension / flexion, abdominal, upper body                             | -did not inhibit strength gains  |
| (Bishop, Jenkins, Mackinnon, McEniery, & Carey, 1999) | 21 female cyclists                  | High Resistance / Low Reps                              | parallel squats  | -increased strength<br>-no change in endurance   |
| (Hennessy & Watson, 1994)                             | 56 male Rugby players               | 2 days high intensity at +70% 1RM<br>1 day 2 sets of 10 | squats, hamstring curls, calf raises, lunges, abs, and upper body                                    | -improved endurance<br>-increased upper body strength<br>-inhibited lower body strength gains  |
| (Hickson, Rosenkoetter, & Brown, 1980)                | 9 men recreational                  | High Resistance / Low Reps at 80% 1RM                   | Squats, knee flexion / extension, leg press, calf raises   | -increase running time to exhaustion<br>-no change in $\dot{V}O_{2max}$                        |
| (Hickson et al., 1988)                                | 6 males/2 females recreational      | Heavy Resistance/Low Reps at 80% of 1RM                 | Squats, knee extension / flexion, calf raises  | -improved short and long term endurance<br>-increased strength                                 |
| (Marcinik et al., 1991)                               | 18 men inactive or recreational     | 8-12 RM for arms, 15-20 RM for legs                     | Bench press, knee extension / flexion, hip flexion, leg press, squats, sit ups and upper body        | -improved endurance performance  |
| (McCarthy, Agre, Graf, Poznaniak, & Vailas, 1995)     | 3 groups of 10 sedentary males      | 6 RM  | Squats, , knee extension / flexion, calf raises and upper body                                       | -increased $\dot{V}O_{2peak}$<br>-did not inhibit strength                                     |
| (Paavolainen et al., 1991)                            | 15 male Cross Country Skiers        | Explosive Low loads / high velocity                     | Sprints, jumps, bilateral counter movements, leg press, knee extensor / flexion, circuit training    | -increased force<br>-did not inhibit aerobic performance<br>-training volume remained constant |
| (Paavolainen et al., 1999a)                           | 18 male elite Cross Country runners | Explosive Low loads / high velocity                     | Sprints, jumps, bilateral counter movements, leg press and knee extensor / flexion, circuit training | -improved 5km times<br>-improved muscle power<br>-improved RE                                  |
| (Sale et al., 1990)                                   | 16 PE students                      | High reps<br>6 sets of 15-20                            | Leg press, hip flexion / extension, knee flexion / extension, calf raises                            | -found it's better to strength and endurance train on different days                           |

(Hennessy & Watson, 1994; Leveritt et al., 1999). Others believe that CSE training will negatively affect an athlete's fast-twitch muscle fibres, thus impairing agility and speed. Hamilton and Booth (2000) showed that both endurance and strength training can cause fibres to shift away from the fastest fibre type to express slower myosin isoforms exhibiting higher endurance, however resistance trained athletes still get stronger. Although the above adaptations appear to be at opposing ends of the training spectrum, many researchers have noted the positive effects of CSE training on neural activation (McCarthy et al., 1995). For example, Sale (1988) stated that when hypertrophy of muscle fibres occurred with training, the motor unit activation, the number of active units and their firing rate, required to produce a given force decreased. As this neuromuscular pattern is developed, the athlete is able to activate a greater number of motor units with a greater frequency, thus producing an increase in the maximum force potential in a given muscle (Howard, Ritchie, Gater, Gater, & Enoka, 1986). This leads to the possibility that strength training may allow a runner to more fully activate prime movers in specific movements, and to better coordinate the muscles actively being used, thus resulting in a greater net force in the intended direction of movement (Sale, 1988). A study by Higbie and Cureton (1996) showed that increases in neural activation, measured by the electrical excitation of the underlying musculature, and strength were specific to the mode of training. Therefore, alternate methods other than just running, used to train endurance athletes, warrant closer investigation.

## **2.4 Muscular Hypertrophy in CSE Training**

The effects that have been observed when combining strength and endurance training have, for the most part, shown that CSE training interferes with fibre hypertrophy patterns compared to programs employing strength training alone (Nelson, Arnall, & Loy, 1990). CSE training inhibits the gains in muscle mass usually associated with strength training. However, since improvements in muscular strength related to power and force, not improvements in muscle mass, are the endurance athlete's goal, this should not pose a problem for the endurance runner.

A study by Tesch (1987) showing muscle enzymatic changes in athletes after a six-month strength only training program, acknowledged that long-term strength training was associated with muscle hypertrophy but that the load used, rather than the volume or rate of training, dictated the magnitude of hypertrophy. This study investigated the effects of different types of strength training, when performed without endurance training, on skeletal muscle and provided useful information for endurance athletes wishing to incorporate strength training into their regimen. These type of studies investigating specificity of training lead us to the phenomenon that many scientists have seen in which athletes performing CSE training will show gains in strength without the significant hypertrophy that is usually seen when strength training is performed in isolation. The amount of muscular hypertrophy can be minimised, depending upon the type of strength training performed. For example, one specific type of strength training known as maximal power output training relies less on heavy loads and emphasises the rate of force production and optimal power output. This type of training produces less muscle hypertrophy than that seen during typical heavy-resistance strength training (Hakkinen, 1994; Tesch, 1987). This demonstrates the importance of a carefully planned strength training program to improve muscular strength, coordination and running economy, with minimal muscular hypertrophy.

Other methods of strength training have also been used to yield benefits in endurance performance. A study by Johnston, Quinn, Kertzer, and Vroman (1997) utilised free-weight strength training techniques (2-3 sets of 8-15 repetitions) in order to improve endurance performance. In other work by Hickson, Rosenkoeiter, and Brown (1980) heavy resistance training (3-5 sets of 5 repetitions) was employed in order to increase endurance capacity. Both methods of strength training were successful in producing the desired improvements in the runner's economy with little or no impact on body composition.

Further supporting evidence was provided in a study by Paavolainen et al. (1999a) which suggested that improvements in sprinting and / or explosive-force-production capacity, especially in endurance athletes, might be due to neural adaptations without observable



muscle hypertrophy. Results showed that simultaneous explosive strength and endurance training significantly improved running economy and 5km running time. Another practical application of this theory by Johnston et al. (1997) used CSE training on a group of female distance runners. The athletes performed strength training three days per week and found that although strength enhancement was clearly evident, it was not accompanied by significant increases in body mass, fat free mass, percent body fat, or body circumference measurements. Research in this area clearly indicates that the potential exists for an endurance athlete to develop strength, without the accompanied increases in girth or muscle size.

## **2.5 Specificity of CSE Training**

Many of the studies presently available in the area of CSE training fail to investigate the effect of strength training on endurance related performance. Paavolainen et al. (1999a) acknowledged this dilemma, stating that the critics of strength training for endurance runners have mainly focused on studies where the emphasis of the overall program was on strength development alone. However, through a correctly structured strength-training program, endurance athletes may see improvement in their competition times (Paavolainen et al., 1999a).

Scientists know that athletic economy tends to be task specific and furthermore, that the principle of specificity suggests that athletic training is most effective when the training activity is similar to the target activity (Bishop et al., 1999; Ebben, 2001; Hickson et al., 1988). The effectiveness of a strength training program is determined by appropriate selection of the strength training method incorporated into the training regimen. A study by Getmanets et al. (1989) further explained that the fundamental principle in the selection of the strength development program is their dynamic similarity to the muscle contractions that occur in the competitive event.

Table 2 which has been adapted from a review by Ebben (2001), shows an example of some of the different types of training and their potential effects on power development. Running is a relatively high velocity activity that requires speed of movement. Since the mass of the object to be moved is only the athlete's own body mass, the force / velocity ratio that is needed for endurance running should be adjusted accordingly. Olympic lifts and maximum power training both require a sound strength base, with Olympic lifts also requiring a level of technical proficiency. Plyometric exercises typically require a sound strength base prior to being included into an athlete's program (Howard, Ritchie, Gater, & Enoka, 1986). Plyometrics such as box jumps and bounds can be hazardous, due to the high impact thus potential for injury, in subjects inexperienced with strength training (Allerheiligen, 1994).

## **2.6 Running Economy**

A runner's "efficiency" and the ability to improve it have long been topics of interest for scientist, athletes and coaches, as they relate to both inter- and intra-individual differences in the relationship of  $\dot{V}O_2$  and running speed (Daniels, 1985). Successful endurance performance has been said to be directly linked to a variety of variables such as,  $\dot{V}O_{2max}$ , lactate threshold, anaerobic threshold, economy of energy expenditure, running economy and other measurements which can be used in order to predict athletic performance (Bassett & Howley, 1997). While the most common method used to predict aerobic ability has been the assessment of  $\dot{V}O_{2max}$ , recent research suggests that success in distance running is most likely multifactorial and that other factors such as running economy may be a better indicator of endurance performance (Bulbulian, Wilcox, & Darabos, 1986). More economical runners tend to have identifiable patterns in their running mechanics which might not be related to any specific set of variables, but instead would be an overall combined effect from a large number of variables (Williams & Cavanagh, 1987). This "overall combined effect" can then be measured by any changes in steady-state oxygen consumption, giving the scientist the unifying, quantifiable measurement known as running economy.

**Table 2**

*Relative Force / Velocity Characteristics of Training Methods to Develop Power*

| Training method        | Capacity for force component of power | Capacity for velocity component of power |
|------------------------|---------------------------------------|--|
| Strength Training      | High                                  | Relatively Low                           |
| Olympic Lifts          | Moderate                              | Moderate                                 |
| Maximum Power Training | Relatively Low                        | Relatively High                          |
| Plyometrics            | Low                                   | High                                     |

Martin and Morgan (1992) defined running economy as the aerobic demand ( $\dot{V}O_2$ ), at a given sub-maximal running speed. The authors acknowledged that running economy could be responsible for improvements in performance times for CSE trained subjects, as opposed to their endurance only trained counterparts. Many factors can contribute to a person's RE. A scientific review by Daniels (1985) identified the following six key factors that may influence a person's "aerobic demand" at a particular pace: (1) age; (2) air or wind resistance; (3) body temperature; (4) stride length; (5) weight added to or taken away from the body; and (6) training. While the athlete is somewhat limited to changes made in the first five variables, they have a large degree of control over the training program that is used. Therefore, one way to improve performance may be to improve RE via improvements in strength, muscular power and core stability.

A study by Johnston et al. (1997) tested this theory by studying the effects of a strength training program on 12 female distance runners. They hypothesised that in regard to running economy, any changes that would allow a runner to use less energy at a given speed should reduce the demand of oxygen for the same absolute effort. Working at a lower percentage of  $\dot{V}O_{2max}$  may allow a runner to run longer, at the same or faster speed, with the same relative effort. The results of this study found a significant improvement in running economy, lending credibility to the idea that a greater total body strength may lead to changes that would create improvements in the athlete's running style, allowing a runner

to do less work at a submaximal running speed (Johnston et al., 1997). For athletes who run long distances, the small amount of effort saved with each mile through an improved running economy would allow the athlete to run further with less fatigue. In agreement with this idea, a review by Bassett et al. (1997) outlined the foundation of the running economy idea by stating that, if two runners have the same  $\dot{V}O_{2max}$  and the ability to sustain the same percent of that  $\dot{V}O_{2max}$  during a run (they are running at exactly the same  $\dot{V}O_2$ ), the more economical runner will run faster.

Any changes in an athlete's RE could result in an improvement in performance resulting from even a minimal amount of energy saved with every step. For athletes who run long distances in competitive events, this amount of energy saved could add up to a significant "competitive edge" to the athlete with the better RE. For elite athletes, even small improvements in performance are crucial and while the margin of difference in seconds becomes less and less the more skilled the field, improving an athlete's RE could mean the difference between winning and losing. Further evaluation of training methods show that strength development may be particularly important since  $\dot{V}O_2$ , a key predictor of endurance performance, typically does not change after 12-18 months of training (Ebben, 2001).

A study by Paavolainen et al. (1999) which showed improved 5-km times in endurance runners, was among the first to demonstrate that improvements in endurance performance may in fact be enhanced by strength and power training. In this study, by combining explosive-strength training with endurance training, times were significantly decreased in a group of endurance runners. The results of the study showed that times were significantly improved despite no improvements in  $\dot{V}O_{2max}$ . Further discussion stated that improvements in 5-km times were most likely due to improvements in neuromuscular characteristics and RE (Paavolainen et al., 1999a). This past research clearly indicated a direct relationship between strength training and improvements in RE. From the limited amount of studies that have investigated the effects of combined strength and endurance training on

endurance performance, any enhancement of performance has been attributed to an improvement in RE.

The value of explosive strength training was further established in a recent study by Spurr et al. (2003). The authors hypothesised that a 6-week plyometric training program would result in an increase in lower leg musculotendinous stiffness (MTS), allowing the subjects to achieve greater propulsion for the same or less energy cost thereby improving running economy and running performance. Results showed that the plyometric program led to improvement in 3-km running performance, running economy and MTS. While acknowledging that further research is needed, the authors proposed that changes in stride length or stride frequency, may result in athletes achieving greater forward propulsion per foot strike at a decreased energy cost, and may consequently improve running economy.

The ability of a runner to efficiently utilise energy available to him / her affects, to a large degree, the runner's success in competitive endurance events. The aerobic demand of a particular running pace is the steady-state  $\dot{V}O_2$  (Daniels, 1985). This relationship between running velocity and energy expenditure is referred to as "running economy" (RE). If an athlete is able to use less oxygen at a given speed, then the oxygen demand will also be reduced allowing one to run longer at the same or faster velocity with the same relative effort (Johnston et al., 1997).

## **2.7 Summary**

Although there has been much debate as to why CSE training should or should not be pursued, this study seeks to examine a very practical question to athletes and coaches alike, that being: Can the addition of strength training yield improvements in 3km performance times in recreational female endurance runners? There is little research showing the actual effects of CSE training on a runner's performance times. Since performance times are the bottom line to coaches and athletes, this proposed study will focus on comparison of the athlete's race time, in order to show more relevant and applicable results. Any changes in

performance time will be investigated as the result of improved running economy through gains in muscular strength.

Studies have shown that a possibility exists to use strength training in order to stimulate neural adaptations which might enhance an endurance runner's ability to generate a greater amount of force in the intended direction of motion, thus providing the athlete with an advantage over his / her competitors (McCarthy et al., 1995; Sale, 1988). The importance of training movements that are specific to running has been demonstrated and must be carefully considered when designing an appropriate training program (Bishop et al., 1999; Ebben, 2001; Hickson et al., 1988). For the purposes of this study, the type of strength training, which involves 1-5 repetitions per set with maximal weight, is the most appropriate or task specific method of strength training with recreational endurance runners and therefore will be used in the application of the present study.

## **CHAPTER THREE**

### **3.0 MATERIALS AND METHODS**

#### **3.1 Subjects**

Sixteen active women between the ages of 17-27 years participated in this study. Two training groups were formed they being; an endurance training only group (control group, n=9) (mean height = $165.7 \pm 7.0$  cm, mean mass= $59.8 \pm 5.6$  kg, mean age= $20.4 \pm 4.1$  yrs) and an endurance and strength training group (experimental group, n=7) (mean height= $162.1 \pm 17.0$  cm, mean mass= $65.8 \pm 8.9$  kg, mean age= $21.0 \pm 1.9$  yrs). Subjects at the time of testing were not participating in a structured training program and were free of any contraindications to training. Further, subjects had not participated in a strength-training program for at least three months prior to the study and were instructed not to participate in any other type of strength training program during the course of the study. Subjects were recruited from Edith Cowan University and various local Athletic clubs. The inclusion criteria was a 3km performance time of 20 minutes or less. Subjects read the project Information Sheet (Appendix A) then signed the Document of Informed Consent (Appendix B) and completed a Medical Questionnaire (Appendix C). Ethical approval for the study was provided by the Edith Cowan University Human Research committee.

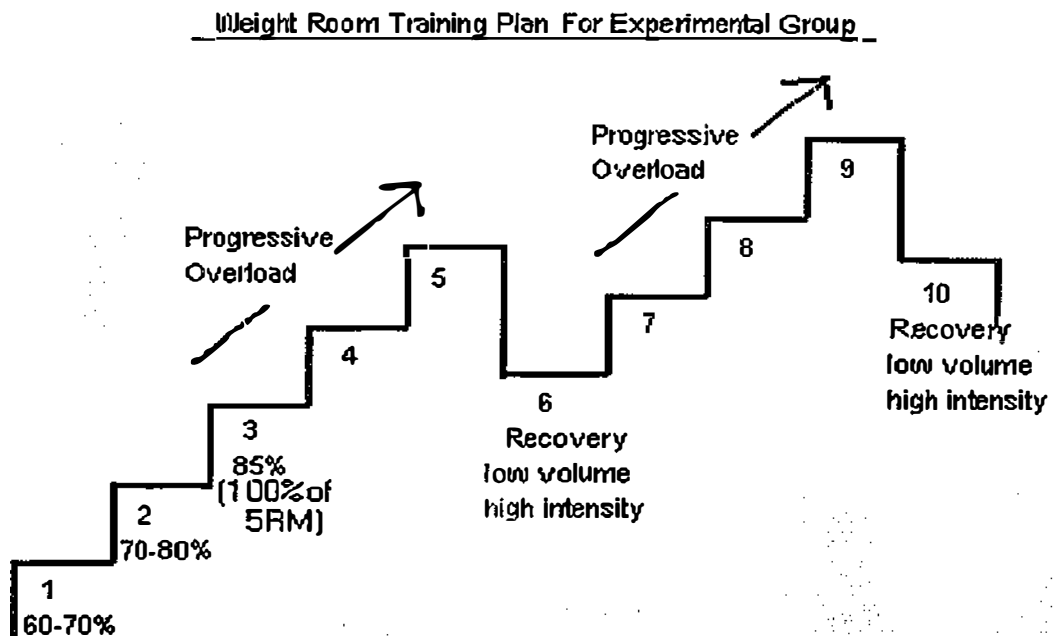
#### **3.2 Outline of Training Programs**

##### **3.2.1 Strength Training**

The experimental group performed strength training at 7:45am on Monday, Wednesday and Fridays, during this time. Exercises consisted of lower limb, upper limb and core body stability strength training exercises. The strength training exercises included: parallel

squats, calf raises, hip extension, hip flexion, hamstring curls, seated row, bench press, sit ups, leg lowers, and back extension.

All strength exercises were performed using three sets of five repetitions. They were initially performed at an intensity of 60-70% of 5RM in week one and 70-80% of 5RM in week two in order to allow for anatomical adaptation. Beginning in week three, strength training then followed the progressive overload principle, such that the weight lifted increased with strength gains. The periodisation plan also included two separate weeks for recovery, one in week six and the other in week ten. These unloading microcycles consisted of only one high-intensity training session during the week. Each strength training session lasted approximately one hour in duration. The outline of the training plan is shown in Figure 1 and an expanded outline of the training plan is given in Appendix D.



*Figure 1* Periodisation plan for the experimental group



### 3.2.2 Endurance Training

Endurance training was performed by both the experimental and control groups running together, at 3:30pm on Monday, Wednesday and Friday's, for ten weeks. For the experimental group, the weight training and endurance training was separated by an eight hour time period to allow for adequate recovery between training sessions and ensure that training quality was not diminished. Endurance training sessions were designed specifically targeting 3km race performance. Workouts emphasized the development of endurance, long and short interval training, and race development (Table 3 and Appendix E). Training sessions were approximately one hour in duration and incorporated a warm-up and cool-down with associated stretching exercises.

Table 3

*Details of Methods Used for Endurance Training*

| Energy System                                  | Heart Rate Range | Training Method  |
|--|------------------|--|
| For endurance base:                            |                  |  |
| Aerobic Base                                   | 130-150bpm       | 15-30 minutes<br>Continuous Running                                |
| Anaerobic Threshold                            | 150-175bpm       | 15-30 minutes Continuous Running /<br>4-8 minutes Interval Running |
| For race development:                          |                  |  |
| $\dot{V}O_{2max}$                              | 180-190bpm       | 3-5 minutes Interval and Repetition<br>Running                     |
| Anaerobic Endurance /<br>Lactic Acid Tolerance | near max         | 30sec-3 minutes Max Heart Rate<br>Intervals                        |

**Note:** Heart rate is given only as a guideline, as each individual's maximum heart rate was different.

### **3.3 Procedures**

Subjects were tested both before and after the 10-week training program on all variables. The pre- and post-testing consisted of two separate sessions allowing for 72 hours between each testing day. Testing included:

1. A 3km timed run, performed one week prior to the beginning of the training program and three days after the program's completion
2. Body composition and girth measurements
3. Running economy and  $\dot{V}O_{2\text{ peak}}$
4. Muscular strength assessed using a 1RM.

Subjects were also required to keep a training log, which included any physical activity done outside of the training program. All data, with the exception of the timed run, was collected at the Joondalup campus of Edith Cowan University. The 3km timed run was tested at the Perry Lakes Stadium track.

#### **3.3.1 3km Timed Run**

Participants ran 3km on an outdoor rubberised athletic track in order to assess running performance. In an attempt to simulate a race type environment, all subjects were tested together and were provided with verbal encouragement. A pilot study was conducted in order to evaluate the reliability of the 3km-timed run as an appropriate assessment of endurance performance. The results of this study are outlined in Section 3.4.1.

#### **3.3.2 Body Composition and Girth Measurements**

Body composition was assessed via skinfold calliper measurements, on the right side of the body at the following four sites: bicep, tricep, subscapular and suprailiac. Skinfold calculations for the bicep and tricep were measured at the anterior and posterior mid-acromiale-radial lines. Skinfold testing for the subscapular fold was measured at a 45 degree angle laterally and obliquely downward from the scapula. The suprailiac fold was

tested medially downward at about a 45 degree angle at the point where the iliospinale landmark to the anterior axillary border intersects the superior border of the ilium.

Relaxed arm, waist, thigh and calf girth were also measured. Arm girth was measured at the mid-acromiale-radiale level. Waist girth was measured at the most minimal point of the trunk. Thigh girth was measured at the gluteal line with both feet together. Calf girth was measured at the most maximal width with weight distributed evenly on both feet. Measurements for both body composition and girth were taken three times at each site, with the mean of the three measurements being recorded.

### 3.3.3 Running Economy and $\dot{V}O_{2\text{ peak}}$

Running economy was measured via a seven minute, level grade submaximal test on a Trackmaster<sup>TM</sup> treadmill. The testing protocol was based on the methods used in a previous study conducted by Johnston et al. (1997). Runners performed a five minute warm up followed by a five minute recovery. Subjects were instructed to run at a pace that was equivalent to their fastest 3km race pace, as determined by their time trial conducted seven days earlier. The pace used for the post-test running economy measure was the same as the pre-test velocity. Since each subject's race pace varied, the treadmill velocity during testing was individualised. Ventilation and  $\dot{V}O_2$  for every 30-second period was measured using a CPX/D Medgraphics Cardiorespiratory Diagnostic System (TM500 JAS Manufacturing Texas, Medical Graphics Corporation St. Paul, MN U.S.A.). A steady state oxygen consumption was determined when  $\dot{V}O_2$  and HR measurements became stable. Once this steady state was reached, inspired and expired air was measured in order to determine the oxygen uptake for that pace. An average was taken between minute five and minute seven once steady state was reached, with this value representing the subject's running economy. A pilot study was conducted in order to evaluate the reliability of this running economy test and the details of the study are presented in Section 3.4.2.

At the completion of the running economy protocol, subjects slowed to walking pace until heart rate measurements reached below 120bpm. Subjects then continued the treadmill run at the same speed, with the first minute being run at 0% treadmill grade. The grade was then increased by 1% every minute thereafter until the subject reached volitional exhaustion. Metabolic data was recorded in 30-second intervals and heart rates were recorded every minute. A plateau of oxygen uptake and heart rate and a respiratory exchange ratio of at least 1.1 were the criteria used to determine if  $\dot{V}O_{2peak}$  was achieved.

### 3.3.4 Muscular Strength

Subjects were familiarized with the strength testing exercises, in a mandatory “Weight Room Orientation Session” one week prior to testing. Before strength testing, subjects performed a warm-up set of 10-12 repetitions at a light weight, followed by stretching. Muscular strength was then assessed by testing the maximum amount of weight that could be lifted in one repetition (1RM) for hamstring curl, parallel squat, calf raise and bench press. Subjects performed multiple single repetitions of each exercise, with three minutes between attempts and used progressively heavier weight until the 1RM was achieved. The rest interval between repetitions was between one and five minutes, with the optimal number of single repetitions ranging from three to five, in attempt to minimise confounding of testing due to fatigue (Brown & Weir, 2001).

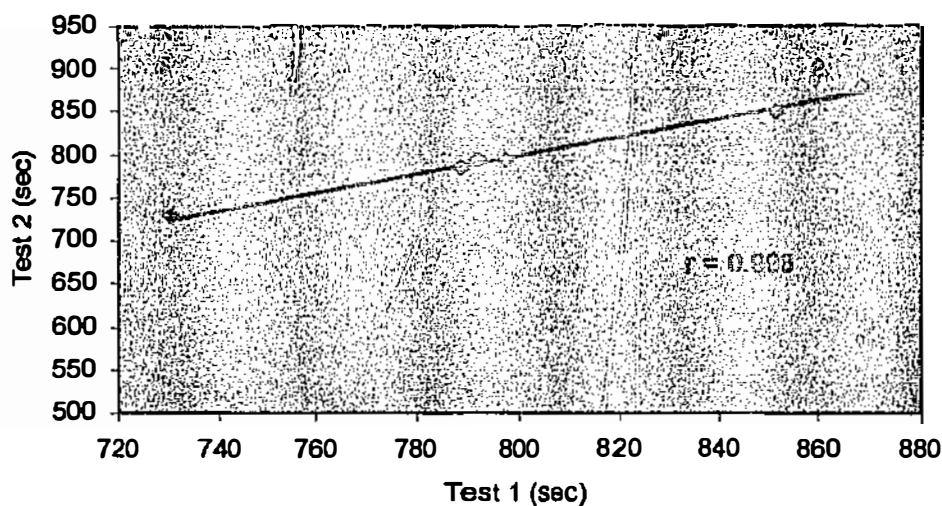
## 3.4 Reliability of Selected Performance Measures

### 3.4.1 Reliability of the 3km Timed Run

The assessment of a runner's performance potential has previously been measured in a variety of ways. As the primary variable in this study was 3km run performance time, it was deemed necessary to examine the reliability of this measure. Six active females aged between 18 and 23 years volunteered to participate in this portion of the study. Subjects were supplied with an information sheet explaining the protocol of the study and any requirements involved. Subjects were instructed to maintain normal activity levels during the testing phase and to keep a journal of any activities done outside of testing.

Two 3km-timed runs, separated by exactly one week, were performed by each subject on a flat, grassy surface. The field was measured prior to testing and was equivalent to 400m per lap. Therefore, testing consisted of a total of seven and a half laps. For consistency the testing place, time of day, and testing environment were kept as similar as possible on both testing dates.

Each subject was allowed to warm-up and stretch prior to testing and subjects were instructed to wear similar clothing and shoes during both testing dates. The subjects in this study were fitted with a wireless Polar PE 3000 heart rate monitor consisting of a transmitter and a receiver. The accuracy of this specific model has been considered to be one of the most accurate tools and comparable to heart rate measurements recorded by an Electrocardiogram (Seaward, Sleamaker, McAuliffe, & Clapp, 1990). The 3km-running times were recorded on both the wrist monitor as well as on a stopwatch and the mean of these values was recorded. Following each testing session, the subjects were instructed to cool down and stretch. The individual data are reported in Appendix F. Results were analysed using a repeated measures t-test. The data demonstrated that there was no significant difference ( $p < 0.05$ ) between the 3km run times in test one and two. Furthermore, there was an almost perfect correlation ( $r = 0.996$ ) between the tests (Figure 2).



*Figure 2* 3km run time results between performance tests

Heart rates were reviewed to ensure consistency of effort between testing sessions. The test showed no significant difference ( $p>0.05$ ) in heart rate levels between each of the two tests, adding credibility to the accuracy of the results. Measures of the 3km timed run separated by a one week interval were shown to be reliable during the two testing sessions. Therefore, this method of measurement can be used in evaluating an athlete's run performance with a very high degree of confidence.

#### 3.4.2 Reliability of the Running Economy Protocol

RE has been assessed in a variety of ways therefore, it was important to conduct a pilot study to determine the reliability of the RE protocol so that it may be used as a measure of submaximal endurance capacity. Six female subjects aged between 17 and 26 years participated in this portion of the study. Each subject was a recreational or club sport athlete and had been participating in a regular running program for at least 12 weeks. Participants were supplied with an information sheet explaining the process of the study and any requirements involved.

Subjects completed the testing protocol twice separated by one week. RE was measured via a protocol on a Trackmaster™ treadmill. The protocol was based on the methods used in a study conducted by Johnston et al. (1997). Running economy was measured by having participants run for seven minutes at a level grade at a velocity determined from their previous best 3km run performance as determined by a 3km time trial. These values ranged between 1.48 and 2.07 ( $L \cdot min^{-1}$ ). Data was recorded in 30-second intervals and the last two minutes were averaged to determine the oxygen uptake for that pace. Ventilation,  $\dot{V}CO_2$ ,  $\dot{V}O_2$ , and RER for every 30-second period was measured using a CPX/D Medgraphics Cardiorespiratory Diagnostic System. A steady state was determined when  $\dot{V}O_2$ , respiratory exchange ratio (RER) and heart rate (HR) measurements became stable. Inspired and expired air was measured in order to determine the oxygen uptake for that pace. An average was taken between minute six and minute seven, with the value representing the

subject's RE. Subjects were tested again one week later using the same settings and same data collection procedure. The data from the two testing sessions were then analysed to determine reliability.

The raw data listed in Appendix G were analysed using Microsoft Excel. Descriptive statistics are expressed as mean  $\pm$  SD. The technical error of measurement (TEM) and percentage of TEM (%TEM) were calculated using the following formulas:

$$TEM = \sqrt{\sum d_i^2 / 2n}$$

where,  $d_i^2$  is equal to (the difference between test 1 and test 2)<sup>2</sup>, and 2n is equal to (2 x the number of subjects).

$$\% TEM = (TEM / [M1 + M2] / 2) \times 100$$

where; M1 is equal to the mean of the first series of measurements and M2 is equal to the mean of the second series of measurements (Norton et al., 2000).

The results as shown in Table 4 outlined that the RE measurements ( $\dot{V}O_2$ , RER and HR) used to determine the athlete's steady-state oxygen consumption were highly reliable.

Table 4

*Reliability Indices for Running Economy Variables*

| Measurement                         | TEM ( +/-) | %TEM |
|-------------------------------------|------------|------|
| $\dot{V}O_2$ (L·min <sup>-1</sup> ) | 0.14       | 1.87 |
| RER                                 | 0.01       | 0.37 |
| HR (bpm)                            | 4.10       | 0.64 |

### **3.5 Statistical Analysis**

The independent variable was the training program with two levels (endurance training and endurance training with strength training). The dependent variables were the 3km timed run, body composition and girth measurements, running economy,  $\dot{V}O_{2peak}$ , and 1RM values. To determine whether strength training as an additive to endurance would cause a significant improvement in 3km performance in this group of subjects a one-way ANCOVA, with subjects pre-training values as the covariate, was then carried out to assess whether there were any significant differences. Statistical significance was set at  $p < 0.05$ .

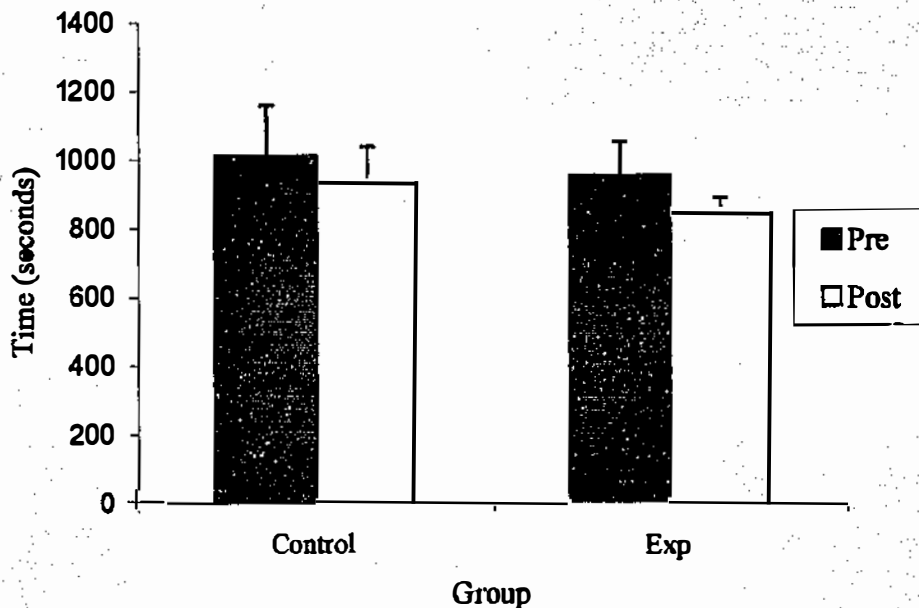


## CHAPTER FOUR

### 4.0 RESULTS

#### 4.1 3km Timed Run

The 3km running time recorded for the control group ( $1012.0 \pm 147.0$  seconds) and the experimental group ( $952.1 \pm 97.8$  seconds) were similar prior to the beginning of training. Both groups improved the time taken to run 3km after the respective training programs. The control group improved to  $934.7 \pm 105.1$  seconds while the experimental group improved to  $845.4 \pm 43.8$  seconds (Figure 3).



*Figure 3* 3km run group results (mean  $\pm$  SD) for the control and experimental groups pre- and post-training

To control for the experimental group's time being non-significantly faster than the control group, prior to the commencement of the training program, a one-way analysis of covariance (ANCOVA) was performed using the subject's pre-training time as the covariate. When controlling for the subject's pre-training 3km time, the strength training intervention did not result in the experimental group's run time being significantly faster than the control group's ( $p < 0.05$ ). However, the control group's improvement was  $77.3 \pm 93.0$  seconds while the experimental group improved their times an average of  $106.7 \pm 91.4$  seconds, thus demonstrating a strong trend evident by a p-value close to statistical significance ( $p = 0.08$ ).

## **4.2 Maximal Strength**

Table 5 presents changes in maximal strength in selected exercises as tested by 1RM for both the control and experimental groups. After ten weeks of training, the experimental group when compared to the control group showed significant ( $p < 0.05$ ) increases in selected measures of leg strength, noticeable by the increased 1RM values for the parallel squat and hamstring curl (Table 5). The control group showed a decrease in the 1RM for the squat of 17.9%, while a significant increase of 6% was shown for the experimental group in the same exercise. Hamstring strength as tested by a 1RM increased for both groups, with the control group showing a gain of 24.7% and the experimental group showing a significant ( $p < 0.05$ ) increase of 45.1%. A non-significant increase ( $p = 0.06$ ) was also observed in the 1RM bench press, a measure of upper body strength, of 11.9% for the experimental group. The control group however, improved by only 1.1%. There were no significant differences found between the training groups for the 1RM calf raise.

## **4.3 Physiological Performance Values**

### **4.3.1 Running Economy Protocol**

Physiological performance data were recorded using two separate protocols, they being; running economy (RE) testing, and the incremental test to exhaustion ( $\dot{V}O_{2peak}$ ). Table 6 shows the effect of the 10-week training program on the physiological variables recorded during both protocols. Interestingly, following the ten-week training program there was a

non-significant increase in RE for both groups. There was a non-significant increase of 1.9% for the control subjects (from  $29.6 \pm 4.6$  to  $30.2 \pm 7.0$   $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) and 6.3% for the experimental subjects (from  $27.5 \pm 3.6$  to  $29.3 \pm 2.6$   $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ). Submaximal heart rate (HR) values recorded during the RE protocol decreased ( $4 \pm 5.4$   $\text{beats}\cdot\text{min}^{-1}$ ) but not significantly for the control group and remained the same ( $0 \pm 5.4$   $\text{beats}\cdot\text{min}^{-1}$ ) for the experimental group. The respiratory exchange ratio (RER) measured during the RE protocol remained unchanged with training in the two groups.

**Table 5**

*Pre- and Post-Training and Resulting Differences in One Repetition Maximum Strength Training Values (kg)*

| Variable       | Control<br>(n=9) |                 |                | Experimental<br>(n=7) |                 |                | F     | p     |
|----------------|------------------|-----------------|----------------|-----------------------|-----------------|----------------|-------|-------|
|                | Pre              | Post            | Diff           | Pre                   | Post            | Diff           |       |       |
| Squat          | 66.2<br>(15.9)   | 62.2<br>(17.3)  | -4.0<br>(4.5)  | 67.6<br>(15.9)        | 79.7<br>(12.0)  | 12.1<br>(9.3)  | 21.35 | 0.00* |
| Calf Raises    | 208.9<br>(45.4)  | 258.3<br>(54.9) | 49.4<br>(46.3) | 225.0<br>(34.8)       | 297.9<br>(53.4) | 72.9<br>(36.5) | 1.35  | 0.27  |
| Hamstring Curl | 35.6<br>(9.2)    | 44.4<br>(8.5)   | 8.9<br>(8.6)   | 37.9<br>(8.6)         | 55.0<br>(6.5)   | 17.1<br>(5.7)  | 8.43  | 0.01* |
| Bench Press    | 28.2<br>(6.2)    | 28.5<br>(6.8)   | 0.3<br>(5.3)   | 37.0<br>(11.4)        | 41.4<br>(10.2)  | 4.4<br>(6.4)   | 4.16  | 0.06  |

**Notes.** Numbers in ( ) represent standard deviation. 1RM, maximal weight lifted on one repetition. \* Indicates significant ( $p < 0.05$ ) difference between experimental and control groups.

Table 6

*Pre- and Post-Training and Resulting Differences for Physiological Performance Values*

| Variable  | Control<br>(n=8) |                |                | Experimental<br>(n=7) |                |                 | F    | p    |
|---|------------------|----------------|----------------|-----------------------|----------------|-----------------|------|------|
|   | Pre              | Post           | Diff           | Pre                   | Post           | Diff            |      |      |
| <i>RE Protocol</i>  |                  |                |                |                       |                |                 |      |      |
| HR (beats·min <sup>-1</sup> )                                   | 174<br>(15.7)    | 162<br>(18.6)  | -13<br>(10.5)  | 166<br>(14.1)         | 156<br>(14.1)  | -10<br>(7.5)    | 0.22 | 0.65 |
| RER   | 0.99<br>(0.05)   | 0.97<br>(0.07) | 0.03<br>(0.06) | 0.97<br>(0.03)        | 0.96<br>(0.03) | -0.01<br>(0.01) | 0.31 | 0.59 |
| RE (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )                    | 29.6<br>(4.6)    | 30.2<br>(7.0)  | 0.6<br>(4.1)   | 27.5<br>(3.6)         | 29.3<br>(2.6)  | 1.5<br>(2.1)    | 0.44 | 0.52 |
| <i><math>\dot{V}O_{2peak}</math> Protocol</i>                   |                  |                |                |                       |                |                 |      |      |
| HR <sub>peak</sub> (beats·min <sup>-1</sup> )                   | 194<br>(6.6)     | 190<br>(9.2)   | 4<br>(5.4)     | 193<br>(6.6)          | 193<br>(5.0)   | 0<br>(5.4)      | 2.34 | 0.15 |
| RER   | 1.17<br>(0.02)   | 1.16<br>(0.07) | 0.00<br>(0.08) | 1.19<br>(0.06)        | 1.20<br>(0.08) | 0.01<br>(0.06)  | 0.42 | 0.53 |
| $\dot{V}O_{2peak}$<br>(ml·kg <sup>-1</sup> ·min <sup>-1</sup> ) | 39.5<br>(6.0)    | 42.3<br>(4.9)  | 2.0<br>(5.8)   | 39.9<br>(5.2)         | 45.1<br>(7.2)  | 5.2<br>(5.6)    | 0.88 | 0.37 |

**Notes.** Values given are means. Values in ( ) represent standard deviations. HR represents heart rate. RER represents respiratory exchange ratio. RE represents running economy.

#### 4.3.2 Incremental Test to Exhaustion

The subject's  $\dot{V}O_{2peak}$  were non-significantly increased, with both training methods during the incremental test to exhaustion, with an average increase of  $2.0 \pm 5.8$  ml·kg<sup>-1</sup>·min<sup>-1</sup> for the control group and  $5.2 \pm 5.6$  ml·kg<sup>-1</sup>·min<sup>-1</sup> for the experimental group. Although the  $\dot{V}O_{2peak}$  values of the experimental group improved (13.0%) more than the control group

(7.1%), the difference was not statistically significant. The subject's  $HR_{peak}$  during the test decreased for both the control group ( $-13.0 \pm 10.5 \text{ beats} \cdot \text{min}^{-1}$ ) and the experimental group ( $-10 \pm 7.5 \text{ beats} \cdot \text{min}^{-1}$ ) however, this did not approach significance. RER during the incremental test to volitional exhaustion did not change for either group. In line with the RE protocol, there were no significant differences found between the control and experimental group's pre- versus post-training physiological performance values.

#### 4.4 Anthropometric Variables

Table 7

*Anthropometric Measurements Pre- and Post-Training*

| Variable       | Control<br>(n=8) |               |               | Experimental<br>(n=7) |                |               | F    | p    |
|----------------|------------------|---------------|---------------|-----------------------|----------------|---------------|------|------|
|                | Pre              | Post          | Diff          | Pre                   | Post           | Diff          |      |      |
| Body Fat %     | 23.7<br>(3.0)    | 22.8<br>(3.3) | -1.0<br>(0.8) | 24.9<br>(4.2)         | 23.9<br>(4.1)  | -0.9<br>(1.9) | 0.02 | 0.89 |
| Body Mass (kg) | 59.8<br>(5.6)    | 60<br>(5.8)   | 0.2<br>(0.7)  | 65.8<br>(8.9)         | 65.3<br>(8.5)  | -0.5<br>(1.3) | 1.13 | 0.31 |
| <i>Girths:</i> |                  |               |               |                       |                |               |      |      |
| Upper arm (cm) | 26.2<br>(2.3)    | 26.1<br>(2.4) | -0.1<br>(0.7) | 28.4<br>(1.9)         | 28.6<br>(1.8)  | 0.1<br>(1.1)  | 0.79 | 0.39 |
| Abdominal (cm) | 68.6<br>(3.8)    | 69.6<br>(4.1) | 1.0<br>(2.0)  | 74.4<br>(6.6)         | 75.1<br>(5.5)  | 0.7<br>(1.5)  | 0.26 | 0.62 |
| Hips (cm)      | 96.5<br>(3.5)    | 95.4<br>(4.7) | -1.1<br>(2.7) | 98.9<br>(7.6)         | 100.1<br>(7.7) | 1.3<br>(2.9)  | 2.57 | 0.13 |
| Thigh (cm)     | 54.1<br>(3.9)    | 54.7<br>(2.0) | 0.6<br>(2.3)  | 55.5<br>(2.8)         | 55.9<br>(3.1)  | 0.4<br>(2.1)  | 0.20 | 0.66 |
| Calf (cm)      | 34.9<br>(1.4)    | 34.8<br>(1.7) | -0.1<br>(0.5) | 36.1<br>(2.0)         | 35.9<br>(2.3)  | -0.2<br>(0.6) | 1.38 | 0.26 |

Note. Values given are means. Values in ( ) represent standard deviations.

On examination of the data, anthropometric measurements were similar between the control and experimental groups prior to the training intervention. For both training groups the percentage of body fat decreased slightly after training, with similar changes of  $-1.0\% \pm 0.8$  and  $-0.9\% \pm 1.9$  for the control and experimental groups respectively. However, the data showed that no significant differences could be found for body composition or girth measurements between the control and experimental groups after the ten week training period (Table 7).

## **CHAPTER FIVE**

### **5.0 DISCUSSION**

#### **5.1 Changes in 3km Timed Run Performance**

The main purpose of the present study was to determine whether a strength training program, when added to an endurance running program, would result in a decrease in time taken to run 3km in a group of recreational endurance runners. Variables related to maximal strength, physiological performance (specifically running economy and aerobic capacity) and subject anthropometry were also measured to assist in explaining any improvement in 3km run time. Although the results between the experimental and control groups were not significantly different, there was evidence of a trend toward increased improvement in 3km time in the experimental group when compared to the control group. Due to the small number of subjects in this study there was low statistical power however, the low sample size evident in this study is typical of past training studies of this type, due to subject compliance and retention (Hickson et al., 1988; Johnston et al., 1997; Paavolainen et al., 1999a; Sale et al., 1990).

Research has investigated the concurrent use of strength and endurance training with contradictory outcomes. It has been previously suggested that combined strength and endurance training results in an “interference effect”, in which the two types of training work against each other. Hennessy et al. (1994) showed that endurance training compromised lower body strength gains and produced no improvement in power or speed. The authors stated that this “interference effect” hindered normal strength and endurance gains when compared to either training method in isolation. Conversely, previous training studies have found that concurrent strength and endurance training may lead to improved endurance performance. A study by Hickson et al. (1988) employed five sets of five

repetitions, with a minimum weight of 80% of each subject's 1RM, three days a week for ten weeks with concurrent endurance training. The program was successful in improving both short- and long-term endurance and also produced significant increases in maximal oxygen uptake. Recent research by McBride, Abel, and Triplett-McBride (2002), determined that heavy resistance training for endurance runners was also associated with a significant increase in maximal strength with a simultaneous decrease in lactate accumulation when performing at high aerobic workloads. This increase in maximal strength was not associated with increases in average mass, fat free mass or lower body fat free mass.

In a study by Bishop et al. (1999) twenty-one endurance trained cyclists failed to show improvements in an endurance performance time trial after 12 weeks of concurrent low repetition / high intensity strength training despite significantly improving maximal strength. However, the authors acknowledged that this was likely due to the lack of sport-specific strength training used (the study used parallel squats only). Other studies have also reported increased strength levels when performing familiar training exercises yet these strength increases did not transfer to improvements in unfamiliar actions which used the same muscle (Rasch & Morehouse, 1957; Wilson, Murphy, & Walshe, 1996). However, results of other research (Hickson et al., 1988; Marcinik et al., 1991) did not agree with the findings of Bishop et al. (1999) as they reported improvements in endurance performance, as evident in time-to-fatigue tests as a result of increases in leg strength. These time-to-fatigue tests however, have been criticised for not being an accurate representation of endurance performance in addition to being unreliable (Jeukendrup, Saris, Brouns, & Kester, 1996). Therefore, it has been stated that a time-trial protocol is a more accurate assessment of endurance performance (Bishop et al., 1999). The above research testifies to the importance of sport-specific movements in training and the importance of selecting sport-specific dependant variables for testing. Consequently, the present study consisted of movement specific strength training exercises and judged improved endurance by a 3km time-trial.



The trend of improvement in the experimental group's 3km run times found in this study is in agreement with other studies that have found enhanced endurance performance when strength training was added to endurance training (Hickson et al., 1988; McCarthy et al., 1995). Concurrent strength and endurance training has been found to substantially increase  $\dot{V}O_{2peak}$ , maximal strength (McCarthy et al., 1995) and improve short-term and long-term endurance (Hickson et al., 1988). The study of Paavolainen et al. (1999a) showed that improvements in sprinting and/or explosive-force-production capacity, especially in endurance athletes, might be due to neural adaptations without observable muscle hypertrophy. In this study ten experimental male, elite cross country runners increased  $\dot{V}O_{2max}$  and decreased 5km running time after nine weeks of explosive-strength training. Another possibility that may explain this finding is that improved running performance may be related to the ability of the neuromuscular system to produce power during maximal exercise when glycolytic and oxidative energy production are high and muscle contractility may be limited (the muscle power factor) as is seen in endurance sports (Paavolainen et al., 1999b).

Millet, Jaouen, Borrani and Candau (2002) stated that for the same level of muscle tension, Type II motor units were recruited preferentially at lower cycle frequency when the force required at each cycle was higher. Therefore, if a runner's stride frequency remains unchanged, improvement in maximal strength as indicated by an improved 1RM could relate to a lower relative peak tension at each stride cycle (for example from 50% to 35% of maximal force) and thus may lead to an increased contribution from the slow-twitch fibres (Millet et al., 2002). Since larger fibres in muscle typically generate more force, resistance-trained runners may be able to exercise longer at an absolute submaximal workload by reducing the force contribution from each active muscle fibre or by using fewer of them (Tanaka & Swensen, 1998). This would inevitably lead to the recruitment of fewer motor units. In conjunction, hypertrophied type I fibres that are capable of greater force generation may allow resistance-trained runners to delay the recruitment of the less efficient type II fibres (Hickson, 1980; Hickson et al., 1988). Although it was beyond the scope of the present study to examine these factors, the fact that improvements in 3km run

times and maximal strength were not associated with changes in muscle girth supports this idea. The hypothesis of Noakes (1988) and other scientists (Green & Patla, 1991; Paavolainen et al., 1999a) that endurance performance may be limited not only by central factors related to  $\dot{V}O_{2\max}$  but also by the muscle power factor seems to warrant further investigation.

## **5.2 Changes in Maximal Strength**

After ten weeks of training, the experimental group showed significant increases in leg strength, noticeable by their increase in 1RM values for the parallel squat and hamstring curl. There was a non-significant increase in strength for both the control and the experimental groups for the 1RM calf raise. A strong trend was observed for an increase in upper body strength in the experimental group for the 1RM bench press. From these results it is evident that strength was increased in the experimental group even though endurance training was also being performed concurrently. These results refute the findings of Hunter, Demment and Miller (1987) who found that 1RM strength began to decline after a 10 week combined heavy resistance and endurance training program. However, these results are in agreement with other studies which found no interference effect in strength gains when combining the two types of training (McCarthy et al., 1995; Nelson et al., 1990).

The subjects used in the present study had little experience in strength training. As a rule, the lower the training age, the more potential for improvement in strength development when compared to athletes who have previously been strength trained (Balabinis, Psarakis, Moukas, Vassiou, & Behrakis, 2003; Dudley & Djamil, 1985). However, related research has been able to show significant increases in strength and endurance performance in both trained and untrained subjects. Hickson and colleagues (1980) were able to show significant increases in strength as well as improved short-term endurance performance despite eight of the nine subjects used in the study having familiarity with weight training thus minimizing the skill aspect involved. Research by the same author has also reported

improvements in strength, short-term endurance and long-term cycling to exhaustion in another study in which only two of the six male and two of the female participants had previous strength training experience (Hickson et al., 1988).

High level endurance runners share one common characteristic: the ability to compete at different distances characterised by different energy-supply and strength characteristics (Atletika, 1991). In addition to having a positive effect on endurance performance, enhanced strength levels can make a given absolute submaximal load relatively smaller, thus leading to improvements in work economy (Hoff, Gran, & Helgerud, 2002). This was further supported in the present study by the experimental group's increased lower body 1RM strength accompanied by a trend of improved time taken to run 3km. The source of the improved run times in the experimental group may have been due to increased maximal strength which may have translated into improved neuromuscular and biomechanical efficiency. Strength training has been shown to increase the force of muscular contraction by enhancing coordination of motor unit recruitment (Bandy, Lovelace-Chandler, & McKittrick-Bandy, 1990).

As previously mentioned, an improvement in biomechanical efficiency results from strength training (E. R. Burke & Newton, 1983; Johnston et al., 1997; Sabo, Bernd, Pfeil, & Reiter, 1996). It is likely that the trend in improved race performance times in the present study was achieved in part via an increase in stride length. Stride length is defined as the distance travelled by the body during one full cycle of motion. Although theoretical at this point, the experimental group may have benefited from an increase in ground reaction force production, thus leading to increased stride length in addition to allowing them to run at the same absolute intensity while using a lower percentage of maximal strength. Further research is needed in this area. An athlete possessing greater general lower limb strength should be able to display a larger stride length and may also be capable of maintaining it during the course of a race, as the athlete's neuromuscular system inevitably fatigues.

A long distance runner is required to run at a high intensity over a long period of time during competitive events. With Newton's second law of motion ( $F=m.a.$ ), a relationship is

described whereby increases in acceleration are associated with the ability to produce force quickly (Brown & Whitehurst, 2003). The athlete's ability to develop force rapidly may also be an important factor for endurance performance (Hoff et al., 2002). Research by Hickson et al. (1988) stated that increases in leg strength were responsible for improvements in endurance performance in cycling. The authors suggested that the increased 1RM in strength exercises decreased the percentage of maximal force required for each pedal thrust, thus altering the fibre-type recruitment during exercise. Furthermore, if a runner can apply an increase in ground reaction force then there may be a corresponding increase in the runner's velocity via the impulse-momentum relationship. Moreover, research has shown that the difference between faster and slower runners is that faster runners are capable of generating a greater amount of ground reaction force (thus increasing stride length) than the slower runners, not by how rapidly the limbs were repositioned in the air (stride rate) (Weyand et al., 2000). Understanding how various training variables and their interactions will affect either force or velocity would seem important in determining how to alter the performance capability of muscle for a given purpose.

Past research has studied the effects of a variety of strength training methods on performance. It has been found that explosive strength training that allows the load to be projected rapidly, as in a throw or jump, produced higher velocity, acceleration, force and power (Newton & Kramer, 1994; Wilson, Wood, & Elliott, 1991). This research would seem to support the suggestion that ballistic types of strength training such as jump squats be included in the training program of an endurance runner. This may be the next logical progression in training for athletes who already have a strength training base. Power output has shown to be maximised in athletes at approximately 30-60% of 1RM (Baker, Nance, & Moore, 2001; Wilson, Newton, Murphy, & Humphries, 1993).

In general, strength training has a multitude of effects that can benefit an endurance runner. Firstly, the athlete who possesses greater maximal strength levels have been shown to also exhibit a greater muscular endurance in the same exercise (Lyden, 1993). Further, there is also a temporary increase in blood pressure during training sessions, which aids in the

blood perfusion of working muscles (Fleck, 1988; Stone, 1992). Strength training also induces ventricular hypertrophy which leads to a corresponding increase in stroke volume (Effron, 1989) and may assist in injury prevention (Henriksson & Tesch, 1999; Kraemer, Deschenes, & Fleck, 1988). Other benefits of strength training include; correction of muscular imbalances, increased bone mineral density, an enhanced connective tissue network (Stone, 1992) and improved neuromuscular and biomechanical efficiency of movement during long-distance events (Lyden, 1993). It is this last factor which likely improved race performance times in the present study. Training-induced increases in the efficiency of the neuromuscular system and capacity of the muscle to generate force result in an improved ability to cope with a submaximal load (Behm & St. Pierre, 1998; Hoff et al., 2002). It follows that, the addition of the strength training program resulted in an increase in maximal strength for the experimental subjects, thus allowing each athlete to run at the same relative intensity while maintaining a faster velocity during racing. A trend was shown in the present results suggesting that in terms of athletic development (as these were fairly inexperienced runners) strength training can assist in preparing the athlete for competitive events. Endurance coaches will train an athlete specifically to gain improvement in run time. With young athletes performing a high volume of endurance training this can cause lower limb and low back injury. A practical application from the findings of this study is that concurrent strength and endurance training can improve endurance athletes run times and also decrease the volume of specific mileage done, thus reducing an athlete's predisposition to injury and offering some protection against future injury with the same absolute amount of mileage.

### **5.3 Physiological Performance Values**

#### **5.3.1 Running Economy**

It was hypothesised that if improvements in race performance were observed for the experimental group, this improvement would manifest itself in the form of an improved running economy, as reported in previous studies (Johnston et al., 1997; Paavolainen et al., 1999a). Surprisingly, from the data generated in this study, there was minimal change in running economy for both training groups. There were no significant improvements in

either the control or experimental group's running economy performance, heart rate, or respiratory exchange ratio values. These results are in agreement with other studies that found improved endurance performance following combined strength and endurance training, in the absence of any changes in  $\dot{V}O_{2\text{submax}}$  (Hickson et al., 1988; McCarthy et al., 1995). This data indicates that the benefits of the combined strength and endurance training used in this study were likely realized when the athletes were running at a faster pace and intensity thus, recruiting the new type IIa fibres.

Research has stated that the level of fitness of the subjects prior to commencement of a study is likely to be a factor in whether or not changes in running economy will be found (Daniels, Yarbrough, & Foster, 1978). The subjects in the present study had little or no strength training experience and were recreationally active runners. Therefore, increases in strength and improvements in running economy might have been expected. The fact that strength training showed a trend to improve 3km performance in the current study without accompanying improvements in running economy suggests that neuromuscular adaptations took place which in turn, improved mechanical efficiency and work economy. These changes may prove important for both recreational and elite runners. Other mechanical factors may have been affected such as an increased stride length. These possibilities will be discussed below.

### 5.3.2 Aerobic Capacity

There was a non-significant improvement in aerobic capacity following both exercise interventions as tested by the incremental test to exhaustion. Due to the small number of subjects in this study there was a low statistical power which likely resulted in the absence of statistical significance. The experimental group increased their  $\dot{V}O_{2\text{peak}}$  values by 13% and the control group increased  $\dot{V}O_{2\text{peak}}$  values by 7.1%. Although these changes were not statistically significant, these increases were reasonably large, in addition to the clinical implication that any improvement in aerobic capacity would certainly be important to race performance. It is also interesting to note that the improvement in aerobic capacity were almost doubled for the experimental group, and this may have in part contributed towards

the non-significantly greater improvement in 3km run time shown by the experimental group. These results are in agreement with other studies which have found that concurrent strength and endurance training improved aerobic power (Dudley & Fleck, 1987; Hunter et al., 1987). A study by Balabinis et al. (2003) examined 26 male basketball players in a pre-season training program which employed concurrent strength and endurance training. The findings of the study showed that concurrent training resulted in significant gains in power, strength and endurance. As also found in the present study, the concurrent strength and endurance training group showed greater gains in  $\dot{V}O_{2\max}$  (12.9%) than the endurance only group (6.8%). In contrast, other studies have found an improvement in endurance performance following heavy resistance strength training without noticeable changes in  $\dot{V}O_{2\max}$  (Marcinik et al., 1991; McCarthy et al., 1995). In a study by Millet et al. (2002) heavy weight training was used on elite athletes in a 14 week training program. Results showed that although  $\dot{V}O_{2\max}$  values were not affected by the addition of strength training to endurance work, the velocity associated with  $\dot{V}O_{2\max}$  significantly increased in the group performing concurrent training while no change was seen in the endurance only group.

Traditional strength training (60-80% of 1RM / 6-15 repetitions) generally has not been thought to increase  $\dot{V}O_{2\max}$  (Hennessy & Watson, 1994; Hurley et al., 1984; Izquierdo et al., 2003). However, it now appears that any exercise stimulus albeit strength or endurance training, that is sufficient in duration and intensity has the potential to ultimately cause conversions within the fast fibre population from type IIB to type IIA (Kraemer, Patton, Gordon, Harman, & Deschenes, 1995). Interestingly, this type of training (heavy resistance / high intensity) causes these usually highly anaerobic (and most fatigable) type of fibres to express slower myosin isoforms and become more aerobic in nature (Hamilton & Booth, 2000). A smaller, more efficient IIA fibre may be advantageous for endurance performance, as increased fibre efficiency would reduce the rate of adenosine triphosphate (ATP) utilisation, and decreased fibre diameter would enhance oxygen delivery by shortening the average oxygen diffusion distance (Tanaka & Swensen, 1998). Strength training has been shown to cause type IIB to IIA fibre type conversion due to these previously quiescent fibres being recruited during heavy resistance work (Staron & Johnson, 1993). A study by

Campos et al. (2002) investigated muscular adaptations at different points along the strength-endurance continuum by using three different types of resistance training protocols. It was found that fibre-type conversion amounted to approximately a two-fold increase in the percentage of converted fibres with a decrease in fibres classified as purely type IIB in all three types of strength-training protocols (Campos et al., 2002). Furthermore, the capillaries per fibre tended to increase in number after training, indicating the formation of new capillaries within the muscle. The authors concluded that capillary growth may have been hidden in past research by the increase in area occupied by the muscle fibres. The possibility exists that fibre type sub group conversion may have been responsible for the greater increases in  $\dot{V}O_{2\max}$  that were observed in the present study in the experimental group when compared to the control group. During the end stages of  $\dot{V}O_{2\max}$  testing, the effort was necessarily high-intensity and as such one could expect fast twitch motor units (and hence the muscle fibres that they innervate) to be recruited. If these type IIA fibres have taken on greater aerobic characteristics, then the athlete should be able to continue for longer before reaching volatile exhaustion and therefore consume more oxygen leading to an increased  $\dot{V}O_{2\max}$ .

### 5.3.3 Changes in Anthropometric Variables

In the past, the dominant argument for incompatibility of combining strength and endurance training is that the physiological responses to the two types of training are different and represent opposite adaptations (Sale et al., 1990). However, it is apparent that the physiological responses to combined strength and endurance training are also unique when compared to either type of training in isolation (Dudley & Fleck, 1987). In order to maximise the benefits of a strength training program while minimising muscle hypertrophy, as desired by an endurance runner, a low repetition / high weights program was used involving sets of five repetitions at varying levels of intensity up to and including 85% of 1RM. Furthermore, the design of the maximal strength training regimen was developed to emphasise neural adaptations and it was expected that the degree of hypertrophy would be minimised as in other research which used simultaneous training because of the increased catabolic processes (Hickson et al., 1980; Hoff et al., 2002).



Perhaps one of the most important findings of this study is the lack of any anthropometric changes which could potentially decrease performance following combined strength and endurance training, such as increased girth measurements, body mass or body composition. No significant differences could be found between the two groups for girth measurements or body mass after the ten-week training period. In agreement with the present study, other studies have also shown that strength development was not inhibited during combined training, and perhaps more importantly, that muscle hypertrophy was not increased in the same way as when strength training is performed alone (Hickson et al., 1988; Leveritt et al., 1999). There was also a non-significant decrease in body fat for the control (-1.0%) and experimental groups (-0.9%) after the respective training programs.

A possible explanation for the increase in strength without accompanying increases in weight or girth is that concurrent strength and endurance training may elicit a different hypertrophic response from either training performed in isolation. It is evident from other research studies that there is a disruption in the pattern of muscle fibre hypertrophy with combined strength and endurance training when compared to patterns commonly observed during either mode of training alone (Dudley & Fleck, 1987; Leveritt et al., 1999; Nelson et al., 1990).

A study by Johnston et al. (1997) utilised free-weight strength training techniques (2-3 sets of 8-15 repetitions) in order to improve endurance performance in a group of female distance runners. The athletes performed strength training three days per week and it was found that although strength enhancement was clearly evident, it was not accompanied by significant increases in body mass, fat free mass, percent body fat, or body circumference measurements. In other work by Hickson et al. (1980) heavy resistance training (3-5 sets of 5 repetitions) was employed in order to increase endurance capacity. Both methods of strength training were successful in producing the desired improvements in the runner's economy with little or no impact on body composition.

This study has shown that an endurance runner should not abstain from adding strength training to their normal running program, due to fears of an increase in body size. In the present study training with five repetitions per set at a 5RM intensity was successful in increasing strength without compromising the endurance runner's typical ectomorphic body type.



## **CHAPTER SIX**

### **6.0 CONCLUSIONS**

#### **6.1 Conclusions**

In the past, it has been thought that endurance runners should avoid strength training (Hennessy & Watson, 1994; Sale et al., 1990). Endurance runners who attempt to incorporate strength training into their program commonly adopt a low weight / high repetition approach. Whether or not this type of strength training optimises training time is of some debate. Although this type of strength training has some benefit, the endurance runner acquires a form of this type of low weight (their body weight) and high repetition (step turnover) training during their running practices. The design of the maximal strength training (SRM) regimen for recreational endurance runners in the present study was developed to emphasise neural adaptations and maximise the benefits of a weight training program, while minimising muscle hypertrophy, in attempt to enhance race performance.

Within the limitations of this study, important findings were as follows:

- Strength training, as an additive to endurance training, caused a trend for improved 3km running times in a group of recreational female endurance runners.
- A group undertaking concurrent strength and endurance training showed significant increases in leg strength, for the parallel squat and hamstring curl and a trend was also observed for an increase in upper body strength during the bench press. The control group's strength levels predictably did not increase.

- An improvement in running economy was not a contributing factor to improvements seen in 3km performance times in the present study. This suggests that other factors, mechanical and muscular, may be responsible for the improvement in the experimental group's 3km performance times. It is highly likely that the trend toward improved race performance times in the present study was achieved via increased lower limb strength which may improve variables such as stride length.
- There was a non-significant improvement in aerobic capacity following both exercise interventions as tested by the incremental test to exhaustion. Although the results were not statistically significant, they support the potential for concurrent strength and endurance training to improve aerobic power in recreational runners. Results indicate that with a larger sample size, statistical significance may have been achieved.
- No significant differences could be found between the two groups for girth measurements, body mass or body composition after the ten-week training period. This suggests that strength training, which incorporates three sets of five repetitions (5RM), will show increases in maximal strength without compromising the endurance runner's typical ectomorphic body type.

In summary, although a distance runner is not interested in inducing muscle hypertrophy, the athlete still desires the highest levels of strength and power that can be generated by a competitively ectomorphic body type. Instead of being seen as a negative adaptation, maximising the benefits unique to each type of training may be advantageous for the endurance runner. In recreational endurance runners, the inclusion of strength training will not significantly affect running economy but will result in non-significant improvements in  $\dot{V}O_{2peak}$  and improved 3km race performance. The results of this study support the use of a combined strength and endurance training plan to improve 3km performance times.

## **6.2 Recommendations for Future Research**

Research tends to measure improvement in endurance performance by various types of physiological laboratory tests. However, as previously mentioned, past studies have

reported increased strength levels when performing familiar training exercises yet the strength did not transfer to improvements in unfamiliar actions which used the same muscle (Rasch & Morehouse, 1957; Wilson et al., 1996). This testifies to the importance of sport-specific movements in training and the importance of selecting sport-specific dependent variables for testing. A missing component of many studies in the related literature is what effect the exercise intervention had on the athlete's performance in the event in which they must compete.

Further research, which investigates several different types of weight training programs on endurance sport performance, is also needed. This same study could be performed using different types of strength training protocols. Comparisons may then be more insightful for determining where the improvements in endurance performance, following a strength training program may stem. A strength only group could also be included in order to test for interference effects in relation to strength gains.

Measurement of additional variables such as lactate threshold, stride length and force production seem to be warranted to help identify where improvements in run performance manifested themselves. Peak lactate could be measured at the completion of a pre- and post-training 3km run, performed at the same absolute pace, in order to identify any improvement in aerobic capacity. Research which investigates the long-term effects of different types of combined strength and endurance training on muscular hypertrophy is also recommended.

Further research is also needed to fully understand the physiological ramifications of combining strength and endurance training and the role of generating a greater amount of ground reaction force (thus increasing stride length). Biomechanical and physiological efficiency are closely linked and should be more extensively researched along with their contributions and interactions with each other.

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**APPENDIX A**

**INFORMATION SHEET FOR PARTICIPANTS**

## **Information Sheet for Participants**

### **The Effect of Strength Training On 3Km Performance In Recreational Female Endurance Runners**

#### **Aims of the Project**

This study is being conducted as part of a research project working towards the principal researcher's Masters of Science degree. One of the unresolved questions in the area of endurance performance is the influence of strength training on certain endurance related variables. Past training programs have all but ignored strength training for endurance athletes. Recent research however, has shown that strength training may be particularly important for endurance runners by improving running economy through improved muscular strength, power and core stability (William, 2001).

The purpose of this study is to develop and implement a combined endurance running and strength training program and to then compare it to an endurance running program alone. Since the most important aspect of performance to an endurance runner is a faster time, the focus of the study will be comparing performance times prior to and after the 10-week training program.

The long-term implication of this study is to establish whether or not a strength training program will benefit endurance athletes in competition when compared to their endurance training alone counterparts.

#### **Requirements of the Subjects**

A. This study is voluntary and you are under no obligation to take part in the study.

You may withdraw from the study at any time without penalty and without the requirement to provide explanation to the investigator.

B. You will be required to:

- Sign a consent form
- Complete a confidential health questionnaire

- Complete two 3km timed runs (one pre and one post training)
- Complete two body composition tests (one pre and one post training)
- Complete two treadmill tests to measure Running Economy and  $\dot{V}O_{2\max}$  (pre and post)
- Complete two Muscular Strength tests (pre and post)
- Complete a 10-week Endurance Running program
- Complete a 10-week Strength Training program (strength and endurance training group only)
- Keep a weekly training log

### Risk of Participating in the Study

The training program will consist of group endurance training three times a week for all participants. An additional strength training program will be added for the experimental group.

A slight possibility of over-training exists for the group performing both endurance and strength training. An appropriate training prescription, running on soft surfaces when possible and ensuring that all participants wear appropriate footwear will minimise this risk. Muscular soreness may also be experienced following training or testing. Should an injury occur during the training program, participants should notify the researcher and appropriate steps will be taken, as all participants are covered by the School of Biomedical and Sports Science medical insurance policy.

### Project Timeline

Semester 1, 2003

Week 1 - Interest Meeting Wednesday @ 1:15pm

Week 2- Pre-Testing

Week 3-Week 10- Training Program

Week 11- Post-Testing

Running training groups will meet at the Joondalup campus three days a week and the session duration will be approximately 1 hour.

Weight training will be held at the Joondalup campus three days a week and will last approximately 1 hour per session.

Final decisions about training times and schedules will be announced at the interest meeting. If you have any questions, or cannot attend the meeting, please feel free to contact me at the e-mail address provided below.

All information collected during this study will be used for the purpose of this project and no other. Data will remain in a locked filing cabinet at Edith Cowan University. All data will remain confidential and will be accessed only by the principal investigators.

Should you have any further questions about the project or have any complaints or concerns about the manner in which the project is being conducted please feel free to contact the principal researcher

**Cherina Rice**

**Edith Cowan University**

**School of Biomedical and Sports Science**

**100 Joondalup Dve, Joondalup, WA 6027**

**9400 5152 or Rice Cherina@hotmail.com**

**Or**

**Dr. Angus Burnett**

**Edith Cowan University**

**School of Biomedical and Sports Science**

**100 Joondalup Dve, Joondalup, WA 6027**

**(08) 9400 5860**

**Or an independent contact:**

**Associate Professor Barry Gibson**

**Edith Cowan University**

**Head of School of Biomedical and Sports Science**

**100 Joondalup Dve, Joondalup, WA 6027**

**(08) 9400 5037**

## **APPENDIX B**

### **INFORMED CONSENT FORM**





## **The Effect of Strength Training on 3km Performance In Recreational Female Endurance Runners**

### **Informed Consent Form**

Thank you for expressing interest in volunteering to take part in this study. The following information is presented in order to enable you to make an informed decision as to whether you wish to participate in this study. The information included outlines the procedures involved, together with the risk and safeguards associated with participation in the study.

This study is being conducted with the aim of gaining a better understanding of the effect that strength training has on endurance performance in runners. The information gained will ultimately help both coaches and athletes alike, to decide the best training program for the athlete.

Should you volunteer to participate in the study, you will be asked to participate in a 10-week training program. Pre and post testing will be conducted in order to measure improvements in 3km performance times, muscular strength, body composition,  $\dot{V}O_{2\max}$  and running economy. The results of the tests will be made available to you at the end of the study. All data will remain confidential to the research team.

### **Risk of Participating in the Study**

The training program will consist of group endurance training three times a week for all participants. An additional strength training program will be added for one group, which will also consist of training three times a week.

An increased possibility of over-training exists for the group performing both endurance and strength training. This risk will be minimised by an appropriate training prescription, running on soft surfaces when possible and ensuring that all participants wear appropriate footwear. Muscular soreness may also be experienced following training or testing. Should an injury occur during the training program, participants should notify the researcher and appropriate steps will be taken, as all participants are covered by the School of Biomedical and Sports Science medical insurance policy. All information collected during this study will be used for the purpose of this project and no other. Data will remain in a locked filing cabinet at Edith Cowan University. All data will remain confidential and will be accessed only by the principal investigators.

I, \_\_\_\_\_ give my consent to participate in the research titled: The Effects of Strength Training on 3km performance times of Middle Level Endurance Runners, on the following basis:

- I have read and understand the Information Sheet for Participants
- I acknowledge that the procedure has been explained to me, including the anticipated length of time it will take, the frequency with which the procedures will be performed, and an indication of any discomfort, which may be expected.
- I understand that my involvement in this study is voluntary and that I am free to withdraw from the study at any stage without penalty.
- I am cooperating in this project on the condition that:
  - The information I provide is kept confidential and participants will not be identifiable
  - The information will be used only for this project
  - The results will be made available to me at the end of the study and any published reports of this study will preserve my anonymity.
  - I have been given a copy of the information sheet and this form, signed by myself and by the principal researcher, Cherina Rice, to keep.

Should you have any further questions about the project or have any complaints or concerns about the manner in which the project is being conducted please feel free to contact the principal researcher:

**Cherina Rice**  
Edith Cowan University  
School of Biomedical and Sports Science  
100 Joondalup Dve,  
Joondalup, WA 6027  
9400 5159 or Rice [Cherina@hotmail.com](mailto:Cherina@hotmail.com)

**Dr. Angus Burnett**  
Edith Cowan University  
School of Biomedical Sports Science  
100 Joondalup Dve,  
Joondalup, WA 6027  
(08) 9400 5860

OR If you would like to contact an independent person:

Associate Professor Barry Gibson  
Edith Cowan University  
Head of School of Biomedical and Sports Science  
100 Joondalup Dve, Joondalup, WA 6027  
(08) 9400 5037

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**Participant / date  
signature**

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**Investigator / date  
signature**

## **APPENDIX C**

### **MEDICAL QUESTIONNAIRE**

**The Effect of Strength Training on 3km Performance Times of  
Recreational Female Endurance Runners  
CONFIDENTIAL MEDICAL QUESTIONNAIRE**

**Contact Details:**

1. Name: \_\_\_\_\_
2. Address: \_\_\_\_\_
3. Phone: \_\_\_\_\_
4. Emergency Contact Person: \_\_\_\_\_
5. Phone: \_\_\_\_\_

**Subject Details:**

6. Date of Birth: \_\_\_\_\_ Age: \_\_\_\_\_
7. Height: \_\_\_\_\_ Weight: \_\_\_\_\_

**Medical History:**

8. Do you have any joint or bone problems? \_\_\_\_\_  
If YES, please describe: \_\_\_\_\_
9. Do you have high blood pressure? \_\_\_\_\_
10. Do you have any cardiovascular problems (such as heart murmur, irregular heart beat, coronary heart disease, etc)? \_\_\_\_\_  
If YES, please describe: \_\_\_\_\_
11. Do you have any respiratory problems (such as asthma, etc)? \_\_\_\_\_  
If YES, please describe: \_\_\_\_\_
12. Are you currently taking any medications? \_\_\_\_\_  
If YES, please describe: \_\_\_\_\_
13. Have you had any other major illness or operations? \_\_\_\_\_  
If YES, please give details: \_\_\_\_\_
14. Is there any reason that you should not participate in a vigorous cardiovascular or strength training program? \_\_\_\_\_

**Physical Activity History**

**15. Have you participate in sporting or recreational exercise activities prior to joining this project?**\_\_\_\_\_

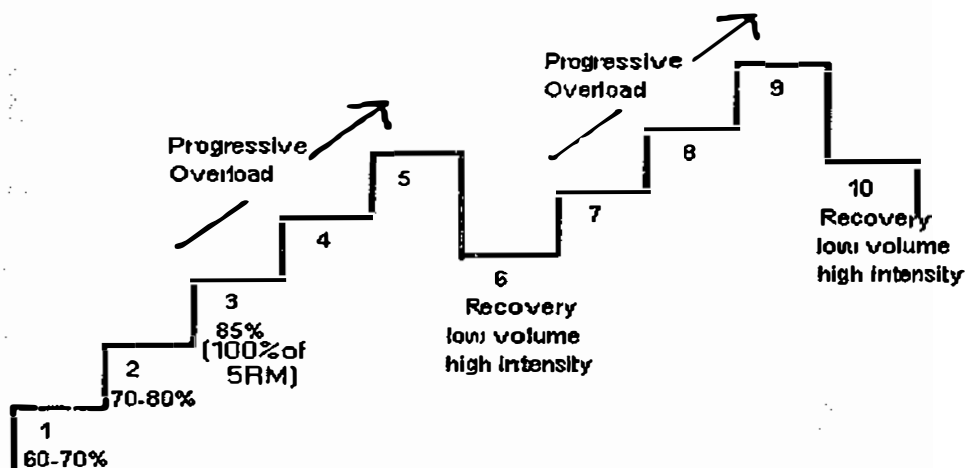
**If YES, please provide details:**

| Type of Activity | Approximate time involved |              | Age   |
|------------------|---------------------------|--------------|-------|
|                  | Years                     | Hrs per week |       |
| _____            | _____                     | _____        | _____ |
| _____            | _____                     | _____        | _____ |
| _____            | _____                     | _____        | _____ |
| _____            | _____                     | _____        | _____ |
| _____            | _____                     | _____        | _____ |
| _____            | _____                     | _____        | _____ |
| _____            | _____                     | _____        | _____ |

## **APPENDIX D**

### **WEIGHT ROOM TRAINING PLAN**

### Weight Room Training Plan For Experimental Group



- I. Weight Room Orientation- Monday March 10 @ 7:15am Room 19.135
  - A. All subjects
  - B. Review parallel squats, bench press, leg curls, and calf raises first and then let the control group leave
  - C. Then go over the other exercises for the experimental group
- II. Pre Training Muscular Strength Testing-Monday August 5<sup>th</sup> @ 7:45am
  - A. All subjects
  - B. Stretch
  - C. Wann-up with 1 set of 10-12 reps at a light weight
  - D. 1 RM test for: parallel squats, bench press, leg curls, and calf raises
- III. Training Program-for experimental group only
  - A. 5RM-3 sets for: parallel squat, hamstring curl, hip flexion, hip extension, seated row (one ann at a time), standing calf raises and bench press
  - B. 1:3 ratio (tempo training)-1 when weight is going against gravity, 3 when weight is going with gravity
  - C. Breathing-at first just concentrate on not holding breath. But more specifically, exhale when weight is going against gravity; inhale when weight is going with gravity.
  - D. 3 sets of 10 for-abdominal crunches, back hyperextension and leg lowers
- IV. Periodisation
  - A. Week 1-2: Anatomical Adaptations
    1. Week 1- 60-70%
    2. Week 2- 70-80%
  - B. Week 3-5: Progressive Overload-85% (100% of 5RM)
  - C. Week 6: Recovery-Low volume / High intensity (1 day @ 3sets of 5RM, nothing for remaining 2 days)
  - D. Week 7-9: Progressive Overload-85% (100% of 5RM)
  - E. Week 10: Recovery-Low volume / High intensity (1 day @ 3sets of 5RM, nothing for remaining 2 days)
- V. Post-training muscular strength testing (same as pre-testing)
- VI. Experimental group will keep a weight room training log, which will stay in the weight room at all times.

## **APPENDIX E**

### **ENDURANCE TRAINING PROGRAM**



## Endurance Training Program Outline

### Basic Principals:

|                 | Aerobic | Anaerobic Glvcolytic | Anaerobic Aclactic |
|-----------------|---------|----------------------|--------------------|
| 1500-1600meters | 50%     | 48%                  | 2%                 |
| 3000-3200meters | 70%     | 30%                  | <1%                |

### For Endurance Base:

|                     |            |   |
|---------------------|------------|---|
| Aerobic Base        | 130-150bpm | Continuous Running<br>15-30 minutes                                 |
| Anaerobic Threshold | 150-174bpm | Continuous Running 15-30 minutes<br>Or Interval Running 4-8 minutes |

### For Race Development:

|  |            |   |
|--|------------|---|
| $\dot{V}O_{2max}$                              | 180-190bpm | Interval and Repetition Running<br>3-5 minutes      |
| Anaerobic Endurance /<br>Lactic Acid Tolerance | Near Max   | Maximum Heart Rate Interval<br>30 seconds-3 minutes |

### Common terms used:

1. **Continuous Running**-Involves running a given distance without rest
2. **Fartlek Training**-Involves alternating fast and slow running over natural terrains. It is the forerunner of the interval training system.
3. **Indian Trail**-Runners form a single file line and set a relatively relaxed pace, while the last runner in the line sprints to the front. The line continues in this sequence, with every runner taking turns sprinting to the front of the line.
4. **Interval Training**-A system of physical conditioning in which the body is subject to short but regularly repeated periods of work interspersed with adequate periods of relief.
5. **Pyramid Running**-Training in which the athletes run a sequence of set distances beginning with the shortest, increasing throughout the workout, and then working back down again.
6. **Repetition Running**-Similar to interval training but differs in the length of the work interval and the level of recovery between repetitions.

7. **Tempo Running**-Athletes run a set distance and alternate speeds between a easy pace for that given distance and a long stride run, usually given by cues such as land marks (light posts) or time (every 3 minutes).

**Monday practices will include:** long continuous running

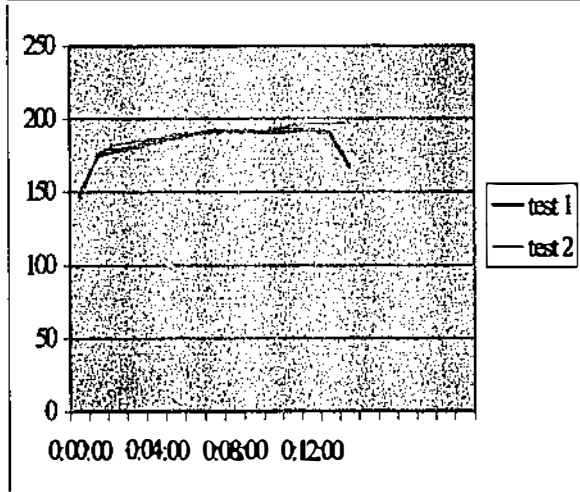
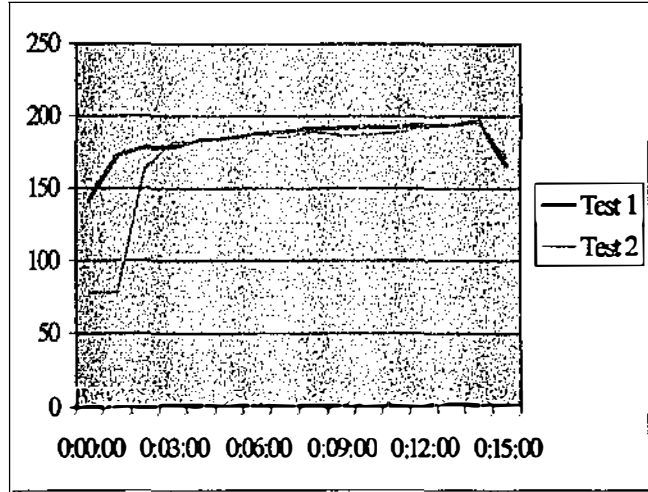
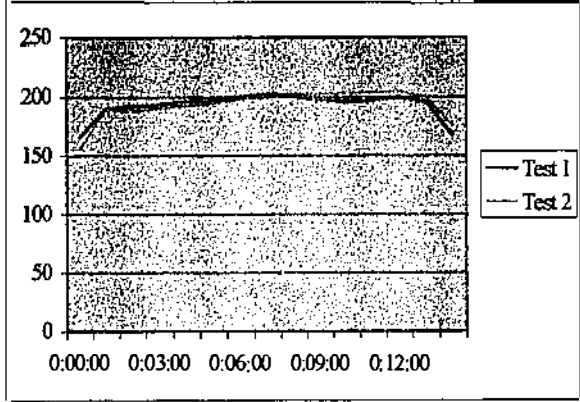
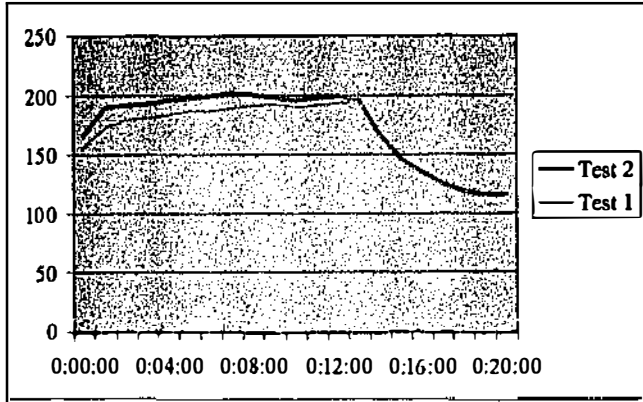
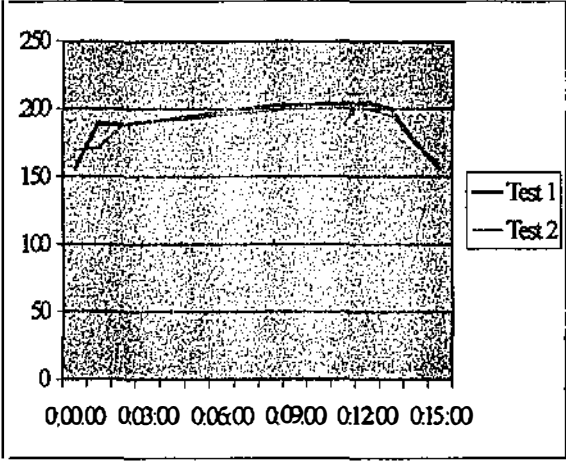
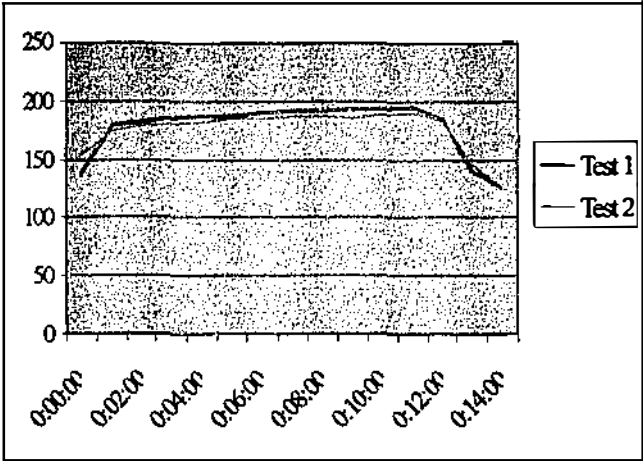
**Wednesday practices will include:** Tempo Running, Pyramid Running, Repetition and/or Long and Short Interval Runs

**Friday practices will include:** Fartlek Runs, Indian Trail and/or Continuous Running

## **APPENDIX F**

### **RELIABILITY OF 3KM RUN RAW DATA**

Subjects 1-6 Heart Rates During 3km Run



| <b>Subject</b> | <b>Test 1 Time<br/>(minutes)</b> | <b>Test 2 Time<br/>(minutes)</b> |
|----------------|----------------------------------|----------------------------------|
| <b>1</b>       | <b>12:11</b>                     | <b>12:09</b>                     |
| <b>2</b>       | <b>13:17</b>                     | <b>13:14</b>                     |
| <b>3</b>       | <b>14:11</b>                     | <b>14:10</b>                     |
| <b>4</b>       | <b>13:09</b>                     | <b>13:05</b>                     |
| <b>5</b>       | <b>14:28</b>                     | <b>14:41</b>                     |
| <b>6</b>       | <b>13:12</b>                     | <b>13:15</b>                     |

## **APPENDIX G**

### **RELIABILITY OF THE RUNNING ECONOMY PROTOCOL INDIVIDUAL DATA**

|         |          | Vo2means |          |             | sum d2   | TEM      | %TEM    |
|---------|----------|----------|----------|-------------|----------|----------|---------|
| Subject | Test1    | Test2    | Diff     | d2          |          |          |         |
| 1       | 1.7792   | 1.904    | -0.1248  | 0.01557504  |          |          |         |
| 2       | 2.0676   | 1.7202   | 0.3474   | 0.12068676  |          |          |         |
| 3       | 1.6522   | 1.4835   | 0.1686   | 0.02842596  |          |          |         |
| 4       | 2.0704   | 1.819    | 0.2514   | 0.06320196  |          |          |         |
| 5       | 1.943    | 1.995    | -0.052   | 0.002704    |          |          |         |
| 6       | 1.92075  | 1.9164   | 0.00435  | 0.000018922 |          |          |         |
| x       | 1.905525 | 1.806367 | 0.099158 |             |          |          |         |
| sd      | 0.16445  | 0.183839 | 0.185267 |             | 0.230613 | 0.138628 | 1.86735 |

|         |          | RER      |          |            | sum d2   | TEM      | %TEM    |
|---------|----------|----------|----------|------------|----------|----------|---------|
| Subject | Test1    | Test2    | Diff     | d2         |          |          |         |
| 1       | 0.892    | 0.914    | -0.022   | 0.000484   |          |          |         |
| 2       | 0.91     | 0.894    | 0.016    | 0.000256   |          |          |         |
| 3       | 0.944    | 0.992    | -0.048   | 0.002304   |          |          |         |
| 4       | 0.992    | 0.966    | 0.026    | 0.000676   |          |          |         |
| 5       | 0.97     | 0.952    | 0.018    | 0.000324   |          |          |         |
| 6       | 0.9125   | 0.912    | 0.0005   | 0.00000025 |          |          |         |
| x       | 0.93675  | 0.938333 | -0.00158 |            |          |          |         |
| sd      | 0.038773 | 0.037639 | 0.028387 |            | 0.002224 | 0.013614 | 0.36531 |

|         |          | HR       |         |       | sum d2 | TEM      | %TEM    |
|---------|----------|----------|---------|-------|--------|----------|---------|
| Subject | Test1    | Test2    | Diff    | d2    |        |          |         |
| 1       | 155      | 147.5    | 7.5     | 56.25 |        |          |         |
| 2       | 136.5    | 146      | -9.5    | 90.25 |        |          |         |
| 3       | 179.5    | 173      | 6.5     | 42.25 |        |          |         |
| 4       | 167      | 164      | 3       | 9     |        |          |         |
| 5       | 160      | 162      | -2      | 4     |        |          |         |
| 6       | 161      | 160.5    | 0.5     | 0.25  |        |          |         |
| x       | 159.8333 | 158.8333 | 1       |       |        |          |         |
| sd      | 14.1939  | 10.32796 | 6.26099 |       | 202    | 4.102845 | 0.64375 |