2007

The effect of concurrent resistance and endurance training on physiological and performance parameters of well trained endurance cyclists

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Masters of Science (Sports Science)
Thesis Proposal

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Date: 23 July 2007

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ACKNOWLEDGEMENT

It would be unjust if I did not start this section by thanking my supervisors, Dr Paul Laursen and Dr Michael McGuigan, firstly for having the belief in me that I would be a suitable masters candidate and then for having the patience and understanding to maintain this belief in me during the long road that has eventually led me to this submission.

I would also like to thank the other staff members and post graduate students that assisted me and often provided valuable information. A special mention must be given to Chris Abbiss and Jeremiah Peiffer for the hours that they spent passing on their knowledge of cycling and laboratory testing procedures to me.

This project would obviously not have been possible if it were not for the willing participants that donated their time. A big thank you to all of the participants for your commitment, willingness to travel, and maximal efforts. I honestly hope that you found the study interesting and enjoyable and that you have managed to improve your cycling.

Lastly, I would like to express my appreciation to my family and my wonderful partner Léat. You were always there supporting me and encouraging me during the good times and the not so good times. Had it not been for all of you I would certainly not be where I am today.

ABSTRACT

Purpose: To investigate the effect of concurrent resistance and cycle training on the physiological and performance characteristics of well trained cyclists. Secondly, this study aimed to investigate the reliability of a new cycling time-trial test that incorporated repeated high-intensity sprint segments, both prior to and after a training intervention, with well trained cyclists.

Methods: Fourteen well trained cyclists completed a series of physiological and performance tests prior to and following a training intervention period. Following the pre tests, subjects were allocated into two groups; a resistance training group (RT; *n* = 7) and a control group (C; *n* = 7). The RT group completed an undulating periodised resistance training program (3/week) for a period of 6 weeks. Testing consisted of a VO_2max test, a 30km time trial with 3 intermittent sprinting periods of 250m and 1km each, 1-RM testing for strength and a repeat jump test to measure power off the bike. After a familiarisation trial, all tests were repeated to allow for assessment of reliability both pre and post training.

Results: Upon completion of the training intervention, the change in time trial and sprinting performance did not differ between the RT and C group. There was however a trend suggesting that sprinting performance may have been negatively influenced with RT (ES 0.5 – 0.9). Nevertheless, the RT group increased strength to a greater degree than the C group ($p < .05$) as well as improving their ability to resist fatigued during a repeated jump test (ES = 0.5). Lastly, all tests performed on the cycle ergometer were found to be reliable both prior to and after a training intervention (CV 1.3 – 3.3; ICC 0.87 – 0.98).

Conclusion: Concurrent training in well trained cyclists does not appear to offer any performance benefits in terms of overall time trial or sprinting performance. However, the increase in strength with RT did not appear to be detrimental to overall performance. Furthermore, testing methods on a cycle ergometer appear to be reliable even after a training intervention.

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1.0 INTRODUCTION

1.1 Background

Successful endurance cycling performance relies on a number of physiological, biomechanical and psychological factors. Arguably one of the most important factors in this matrix of success relates directly to the type and amount of training performed by the athlete. Therefore, researchers have continued to explore the most effective means of training for endurance cyclists (Laursen & Jenkins, 2002). Although elite cyclists are known to average 25–35,000km per year and race for an average of 90 days per year (Lucia, Hoyos, & Chicharro, 2001; Mujika & Padilla, 2001), optimal training programs are vague and it remains unclear as to whether resistance training performed in combination with endurance training is beneficial for cyclists.

Traditionally cyclists begin training by performing extended durations of low-intensity endurance training, resulting in both central and peripheral adaptations to the aerobic energy system (Laursen & Jenkins, 2002). These adaptations occur within those specifically recruited muscles through increases in the capillary and mitochondrial density allowing for more oxygen to be processed by the working muscles (Coffey et al., 2006; Tanaka & Swensen, 1998). Other initial changes include improvements in efficiency and economy of motion (Hawley, 2002). However, in accordance with the principle of specificity, cyclists who perform only low-intensity long-duration training will be at a considerable disadvantage when performing in race conditions that require higher intensity work, such as surges, passing, and sprint finishes (Jung, 2003; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999). Therefore it appears necessary to vary the training intensity and duration in order to optimise endurance performance. The most common form of training variety is interval-training, where athletes repeatedly work at very high intensities for short durations with recoveries at lower intensities (Hawley, Myburgh, Noakes, & Dennis, 1997; Laursen & Jenkins, 2002). Interval training is known to improve peak aerobic power as well as the lactate and ventilatory thresholds (Laursen & Jenkins, 2002) and can elevate sustainable cycling power, as illustrated by the reduction in time taken to complete a 40-km time trial (Stepto, Hawley, Dennis, & Hopkins, 1999; Westgarth-Taylor et al., 1997; A. R. Weston et al., 1996).

An alternative form of training for endurance athletes that has received much attention is concurrent strength and endurance training (Bell, Syrotuik, Attwood, & Quinney, 1993; Häkkinen et al., 2003; Hickson, Dvorak, Gorostiaga, Kurowski, &

Foster, 1988; Leveritt, Abernethy, Barry, & Logan, 2003). Most research in this area has focussed on untrained individuals (Dudley & Djamil, 1985; Häkkinen et al., 2003; McCarthy, Pozniak, & Agre, 2002) or trained runners (Johnston, Quinn, Kertzer, & Vroman, 1997; Millet, Jaouen, Borrani, & Candau, 2002; Paavolainen et al., 1999; Turner, Owings, & Schwane, 2003). This form of training has proved to be successful in improving endurance performance in well-trained runners and cross-country skiers (Hoff, Helgerud, & Wisløff, 1999; Johnston et al., 1997; Paavolainen et al., 1999). However, only a limited number of studies have examined the effect of concurrent strength and endurance training in well-trained cyclists, and the results shown to date are equivocal (Bastiaans, van Diemen, Veneberg, & Jeukendrup, 2001; Bishop, Jenkins, Mackinnon, McEniery, & Carey, 1999; Jackson, Hickey, & Reiser, 2007; Paton & Hopkins, 2005).

The earliest published study which examined concurrent resistance and endurance training in well-trained cyclists was performed by Bishop et al. (1999). After performing 12 weeks of heavy resistance training, female cyclists showed an increase in leg strength but no change in their endurance performance, lactate threshold, or peak oxygen uptake (VO_{2peak}). Similarly, a study by Home et al. (unpublished data cited by Hawley & Burke, 1998) using heavy resistance training found increases in leg strength, but decrements in 40-km time trial performance (Hawley & Burke, 1998). A study by Bastiaans et al. (2001) also examined the effect of concurrent resistance and endurance training. These authors replaced a portion of their endurance training with explosive-type resistance training. Despite a reduction in the volume of endurance training, performance during a one-hour time trial remained constant. Short-term performance as assessed by average power output measured over 30 seconds, remained unchanged in the training group but decreased in the control group, suggesting that explosive resistance training did not compromise endurance performance and may be beneficial if short-term high power outputs are required. Interestingly, these authors employed a combination of double-legged and single-legged exercises in the resistance program. Since the driving phase of cycling is predominantly a unilateral exercise, the principle of specificity suggests that if an athlete incorporates resistance training into their regular cycle training regime then primarily single-legged exercises should be used.

Recently, Paton and Hopkins (2005) used unilateral resistance exercises combined with high-intensity interval training to examine the effect of concurrent strength and endurance training on cycling performance. The authors found significant

improvements over short cycling distances (1- and 4-km). These findings provide support for the use of concurrent strength and endurance training because both resistance training and high-intensity interval training were performed. However it is unclear from this study as to which type of training elicited the greatest endurance performance gains. Another recent study (Jackson et al., 2007) has reported that resistance training was not beneficial for either male or female trained cyclists. In this study, two different resistance training protocols were used (high-resistance/low-repetition and high-repetition/low-resistance) and both interventions showed similar improvements through a delayed onset of lactate accumulation and an improvement in cycling economy. However, there were no significant differences shown compared to the control group that performed cycle training only.

In summary, research examining the influence of concurrent resistance and endurance training on cycling performance is equivocal. Therefore further research is required to examine whether the augmentation of a cyclist's training program with resistance training is able to improve both short-term high-intensity, and long-duration endurance cycling performance. Furthermore, in all previous studies with trained cyclists, resistance training has been targeted to focus only on heavy resistance training, explosive training, or muscular endurance in isolation. However, research has suggested that combined weight training incorporating both high force and high power training is most beneficial for improvements in speed, power and strength (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000). Therefore this study used a combined training program to assess the effect of resistance training in trained cyclists.

1.2 Purpose of the Study

The primary purpose of this study was to supplement an endurance trained cyclists' regular training workload with a six-week resistance training program and to examine its effect on repeat-sprint performance, endurance performance, and physiological variables. Due to the lack of research examining reproducibility of measurements following an intervention period, a secondary purpose of this study was to examine the reliability of physiological measurements prior to and after a brief training intervention.

1.3 Significance of the Study

Whilst a considerable number of studies have examined concurrent strength and endurance training in untrained subjects (Dudley & Djamil, 1985; McCarthy et al., 2002), well-trained cross-country skiers (Hoff, Gran, & Helgerud, 2002; Hoff et al., 1999), and well-trained runners (Paavolainen et al., 1999; Turner et al., 2003), few studies have examined concurrent strength and endurance training on performance and related physiological variables in well trained cyclists. In addition, the studies in cyclists have produced equivocal findings (Bastiaans et al., 2001; Bishop et al., 1999; Jackson et al., 2007; Paton & Hopkins, 2005). Moreover, while a recent study by Paton and Hopkins (2005) showed sprint performance improvements after one-legged strength exercises, the result is confounded by the high-intensity interval training that was performed in conjunction with the strength training program. Therefore, the present study will be the first to examine the influence of a single-leg strength training program in isolation on sprint and endurance cycling performance.

Furthermore, this study will be the first to examine the influence of a multidimensional resistance training approach on trained cyclists. All previous studies in this area have utilised only one form of resistance training (heavy training, explosive training, or training for muscular endurance) throughout the intervention program. The present study attempts to answer the question of whether resistance training is beneficial to overall endurance cycling, which is most often characterised by moderate intensity work periods interspersed with a few high-intensity maximal work efforts (Atkinson, Davison, Jeukendrup, & Passfield, 2003).

1.4 Research Questions

I. What is the influence of concurrent endurance and resistance training on endurance cycling performance and repeat-sprint cycling performance?

II. What is the influence of concurrent endurance and resistance training on leg strength and sustainable power?

III. What is the influence of concurrent endurance and resistance training on physiological (i.e., VO_{2max}) and biomechanical (i.e., power output) variables?

IV. What is the reliability of physiological measurements tested prior to and after a brief training intervention.

1.5 Hypotheses

I. Concurrent endurance and resistance training will improve maximal strength and maximal sustainable power.

II. Concurrent endurance and resistance training will improve repeat-sprint cycling performance and endurance cycling performance by improving peak and sustainable power output.

III. Concurrent endurance and resistance training will increase the power output at ventilatory thresholds, without changes in maximal oxygen consumption.

IV. There will be a high degree of reliability in physiological measurements prior to and following the training intervention period.

1.6 Limitations and Delimitations of the study

1.6.1 Limitations

- All bicycle tests were performed on an indoor trainer and not on the participants own bicycle.
- Testing times for each subject were not held constant and there may be some diurnal variation in results.
- Maximal lifting ability of all exercises was unknown and resistance training intensity was based on subjective measures.

1.6.2 Delimitations

- All subjects performed an individualised yet consistent warm-up prior to the performance trial based on their maximal power output measured on the preceding day.
- Results are representative of only trained male cyclists aged between 18 to 50 years of age.
- The indoor trainer was adjusted to replicate the settings of each participant's own road bike and these settings were maintained throughout the duration of the study.

1.7 Abbreviations

ANOVA – Analysis of Variance

CMJ – Countermovement Jump

ES – Effect size

GXT – Graded Exercise Test

LT – Lactate Threshold

MVC – Maximal Voluntary Contraction

PP – Peak Power

PPO – Peak Power Output

RFD – Rate of Force Development

RJ30 – 30 second Repeated Jump Test

RPE – Rating of Perceived Exertion

RT – Resistance Training

SJ – Squat Jump

TT – Time Trial

TT_{30} – 30km Time Trial

VL – Vastus Lateralis

VM – Vastus Medialis

$\dot{V}O_2max$ – Maximal Oxygen Uptake

VT – Ventilatory Threshold

VT_1 – First Ventilatory Threshold

VT_2 – Second Ventilatory Threshold

2.0 LITERATURE REVIEW

2.1 Introduction

Muscular activity performed for over one minute in duration requires oxygen as the main contributor to adenosine triphosphate (ATP) resynthesis (Gastin, 2001). Thus, elite endurance athletes typically perform extended endurance training sessions well in excess of this duration to enhance the oxygen processing capabilities of their skeletal muscles (Laursen & Jenkins, 2002). While a highly developed aerobic system is paramount to the success of the endurance athlete, a well developed anaerobic capacity might also provide a critical energy reserve to increase the rate of ATP production during high-intensity periods of an endurance event (i.e. surges in pace or the sprint finish) (Jung, 2003; Paavolainen et al., 1999). Endurance athletes could benefit, therefore, from a well developed anaerobic energy system developed via concurrent resistance and endurance training.

This review will examine the influence of resistance and endurance training in isolation, as well as the effects of concurrent resistance and endurance training with reference to key physiological parameters and performance. Moreover, since this thesis is particularly concerned with the outcome of concurrent training on well trained cyclists, the review will expand on this area in greater detail.

2.2 Resistance Training

Resistance training is known to improve muscular strength and power, cause hypertrophy and can even improve muscular endurance (Kraemer & Ratamess, 2004). These various outcomes of training are brought about as a result of manipulating certain variables including the number of sets performed, the intensity of each set and the entire workout, as well as the rest periods between sets and exercises (Campos et al., 2002).

Muscles are constantly involved in exerting the forces required to perform everyday regular activities (Macaluso, Young, Gibb, Rowe, & De Vito, 2003) and therefore certain levels of strength and power are required for functional movements. However, within certain sports (eg. weightlifting and sprinting), strength and power can often play a large part in determining success (Tan, 1999). When resistance training is performed by athletes it is generally categorised as either sport-specific or non-specific. These terms describe how closely the training movements match the actual muscle actions performed during the sporting event. Thus, for optimal improvement,

recruitment patterns performed during resistance training should match the recruitment patterns performed during the sporting event as closely as possible.

2.2.1 Strength, Hypertrophy and Power

Similar training methods are generally employed for improvements in maximal strength and hypertrophy. Both types of training use high loads and low numbers of repetitions (Fry, 2004; Kraemer & Ratamess, 2004). However, some researchers have suggested that a larger volume of training is necessary to maximise hypertrophy (Pearson, Faigenbaum, Conley, & Kraemer, 2000; Tan, 1999). Another difference between hypertrophy and strength training is the duration of rest required between multiple sets. Longer periods of recovery are needed for strength training, while shorter breaks must be used if the training goal is to increase muscle mass (Pearson et al., 2000; Tan, 1999). Maximum strength is often determined by testing the maximum amount of weight that can be successfully lifted only once, known as the one repetition maximum (1-RM) (Newton & Dugan, 2002; Newton & Kraemer, 1994; Tan, 1999) or by assessing the force output during an MVC (maximal voluntary contraction) (Docherty & Sporer, 2000).

Early strength gains following resistance training are believed to be as a result of increased neuromuscular control (Gabriel, Kamen, & Frost, 2006). This is displayed via an increase in the number of active motor units or an increase in the firing frequency (Docherty & Sporer, 2000) and usually occur without any noticeable increases in cross-sectional area. Hypertrophy occurs after resistance training due to an increase in the muscle proteins which results in a larger cross-sectional area (Coffey et al., 2006). There is no standard measure for assessing hypertrophy but various types of imaging technology have been used (Häkkinen et al., 2003; McCarthy et al., 2002).

Since power is the product of force and velocity (Kawamori & Haff, 2004) either one or both of these components must be adequately trained in order to increase power. The ability to produce greater force can be improved via traditional strength training using heavy weight and low repetitions (Hickson et al., 1988). With respect to power training, velocity refers to the speed at which the movements are performed. Therefore explosive type training, at high velocity, with or without additional resistance, has been shown to improve both power and neuromuscular control (Kawamori & Haff, 2004; Paavolainen et al., 1999). This occurs by targeting and training the fast-twitch fibres which are recruited during power exercises.

2.2.2 Specificity

The principle of training specificity explains that for maximum benefit an athlete's training must mimic the movement patterns experienced during competitive performance (Smith, 2003; Tanaka & Swensen, 1998). This results in physiological adaptations specific to the sport and improvement in complex motor skills (Smith, 2003). Previously it was believed that concurrent training for strength and endurance was incompatible because of the lack of training specificity, with early research suggesting that concurrent training compromised improvements in strength development (Dudley & Djamil, 1985; Hunter, Demment, & Miller, 1987) without affect on endurance performance enhancement (Nelson, Arnall, Loy, Silvester, & Conlee, 1990). However, recent research has shown that concurrent strength and endurance training may be beneficial for untrained males (McCarthy, Agre, Graf, Pozniak, & Vailas, 1995). McCarthy et al. (1995) found that untrained males performing concurrent resistance and endurance training displayed no difference in their increased levels of strength compared to a group of previously untrained males who had trained only to increase strength. There was also no difference in aerobic capacity when compared to a group who had trained specifically to improve aerobic capacity. Other research has suggested that concurrent training is beneficial for runners and cross-country skiers (Hoff et al., 2002; Hoff et al., 1999; Johnston et al., 1997; Millet et al., 2002). Indeed, Tanaka and Swensen (1998) have suggested that resistance training could be classified as a form of cross-training because of the associated benefits that it brings to endurance athletes.

When considering whether to include resistance training into the training program of an endurance athlete, there are many factors that one must consider regarding the principle of specificity. As discussed above, there are different types of resistance training (strength, power, and hypertrophy) and it is vital that coaches incorporate only valuable training interventions into their athletes' training programs. Furthermore, there are both sport-specific and non-specific types of resistance exercise (Pearson et al., 2000). The general types of resistance exercise listed above are usually performed using free-weights or machine-weights in a non-specific manner that may engage muscles that might not primarily be recruited during an athletes' sport. Conversely, sport-specific training targets the muscles used during performance and replicates those specific motor patterns against resistance.

Recent research has focussed on the principle of specificity by differentiating lower limb training into bilateral and unilateral exercises (McCurdy, Langford, Doscher, Wiley, & Mallard, 2005; Paton & Hopkins, 2005). By training each leg separately it is assumed that the specific neuromuscular system can be targeted more directly. A recent study in previously untrained subjects examined differences in strength development and power between one group performing only one-legged resistance training and another group performing only double-legged resistance training (McCurdy et al., 2005). In this study no significant difference between bilateral and unilateral strength was found (McCurdy et al., 2005). However, the unilateral training group showed greater gains when tested for unilateral power and matched the bilateral training group when tested for double-legged power (McCurdy et al., 2005). This finding suggests that unilateral resistance training may be more advantageous than bilateral training, as unilateral training does not compromise gains in either single- or double-legged activities. A second study which has examined the effects of unilateral resistance training, found that well-trained cyclists who performed explosive type jumps were able to improve their power output and cycling efficiency when compared to a control group (Paton & Hopkins, 2005). However in this study, the group performing the resistance exercise also performed high-intensity sprinting as part of their training, making it difficult to determine whether the resistance training resulted in any or all of the improvements (Paton & Hopkins, 2005).

To date only one study has examined unilateral resistance training of the lower limbs combined with concurrent endurance cycle training. Bastiaans and colleagues found that this type of training resulted in cyclists being able to match their pre-training maximal 30 second sprint performance, whereas no training resulted in a decrease in maximal short term performance. This suggested that this form of training may be beneficial for cyclists (Bastiaans et al., 2001). It is possible that unilateral resistance training may improve cycling performance because in cycling, instantaneous forces generated by a cyclist consist predominantly of single-legged concentric contractions (Bijker, de Groot, & Hollander, 2002). Further research in this area is needed.

2.2.3 Non-linear Periodised Training

Resistance training programs are designed to suit the desired outcomes of the athlete or individual that is training. This concept is referred to as the principle of specificity. Traditional training over an extended period of time is usually performed within a periodized program that varies the number of sets, repetitions and intensity of

resistance lifted in a cyclical fashion. Two types of periodised programs exist. They are linear programs and non-linear (or undulating) programs. Deschenes and Kraemer (2002) explained that linear programs concentrate on a specific goal, for example strength, hypertrophy, or power training for a specific period of time (1 - 8 weeks) before altering training to target a different area albeit using the previous gains for enhanced effect. Non-linear training focuses on the development of each area at the same time and is the type of training performed in the same week which will vary between targeting muscular adaptations for strength, hypertrophy, and power (Kraemer & Ratamess, 2004).

Whilst this type of training may appear intuitively to have detrimental effects on each particular parameter, it was initially suggested that non-linear training may result in greater strength gains due to more neural stimulation to the muscles as well as allowing a recovery during the lighter training days or weeks (Poliquin, 1988). Baker et al. (1994) found however, that over a 12 week training period no differences existed in the increase in strength and power for groups trained either according to a linear or non-linear periodised program in which the total volume of training was equal between both groups. Furthermore, Newton et al. (2002) have suggested that both strength and power are effectively enhanced when training using a non-linear program for a period of 10 weeks. Young and old men that were training showed similar improvements for strength (squat) and power (squat jump) regardless of age which suggests that a non-linear resistance training program is effective for increasing strength and power output in males regardless of age

When training is only performed for a short duration it may not be necessary or ideal to train according to a linear periodised program. This is because general linear periodised programs are used to avoid overtraining and ensure that peaking occurs at the right time (Stone et al., 1999). It is likely that the beneficial neuromuscular and physiological adaptations from each type of training can have a carry over effect to the next type of training when they are performed only for short periods.

2.3 Physiologically Measured Endurance Parameters

Endurance training is primarily concerned with increasing the amount of oxygen available for use at the cellular level as well as enhancing the transportation of oxygen within the body (Collins & Snow, 1993; Jones & Carter, 2000). Submaximal endurance training results in changes occurring mainly in Type 1 muscle fibres, specifically increases in mitochondrial size and number (Coffey et al., 2006). Due to differences in

physiological adaptation processes, previous research has suggested that concurrent resistance and endurance training were incompatible (Bell, Syrotuik, Martin, Burnham, & Quinney, 2000; Hennessy & Watson, 1994; Kraemer et al., 1995). However, more current research has dispelled the theory of incompatibility and has revealed interesting information about this subject (Jung, 2003; Tanaka & Swensen, 1998). In order to understand the implications of concurrent training, it is necessary to examine the main physiological variables associated with endurance performance. These variables include maximal oxygen uptake ($\dot{V}O_2max$), aerobic and anaerobic thresholds most often determined either as lactate thresholds (LT) or ventilatory thresholds (VT), economy of motion, and efficiency (Atkinson et al., 2003; Coyle, 1999; Hawley et al., 1997; Jung, 2003; Noakes, Myburgh, & Schall, 1990). Each of these variables is discussed briefly below. For more detailed information the reader is referred to recent reviews by Jung (2003) Tanaka and Swensen (1998) and Laursen, Chiswell and Callaghan (2005a). Despite the important contribution that these physiological variables make on endurance exercise, the most accurate predictor of performance recorded during a graded exercise test is the peak velocity or peak power attained (Noakes et al., 1990).

2.3.1 Maximal Oxygen Uptake

Originally $\dot{V}O_2max$ was believed to be the most important physiological determinant of endurance performance because it is a measure of the maximum amount of oxygen that can be processed for aerobic energy production (Laursen et al., 2005a). Recent studies have found that $\dot{V}O_2max$ of subjects has remained stable (Hickson et al., 1988; Paavolainen et al., 1999) when participants performed concurrent strength and endurance training. These findings illustrate that athletes are able to maintain their endurance capacity if they add resistance training into their regular training regime (Hunter et al., 1987). This is consistent with other findings that have suggested that $\dot{V}O_2max$ in trained athletes will stabilise and that performance improvements can be attributed to other factors such as thresholds and economy of motion (Jones & Carter, 2000). Since endurance performance has often been shown to improve without changes in $\dot{V}O_2max$ (Hawley et al., 1997; Hawley & Stepto, 2001) maximal oxygen uptake should not be the sole variable used to determine endurance performance (Lucia et al., 2001). $\dot{V}O_2max$ is nonetheless important, illustrated by fact that it is often used as a marker to distinguish individuals as being either trained, well-trained or elite (Jeukendrup, Craig, & Hawley, 2000). It is however necessary to adopt a holistic

approach when interpreting physiological changes and to include $\dot{V}O_2$max along with other measurements in the analysis.

2.3.2 Thresholds

There are two markers that are commonly used to assess the so called 'anaerobic threshold' of an individual. These include the lactate threshold (LT) and the ventilatory threshold (VT) (Docherty & Sporer, 2000) and both have been shown to be good predictors of endurance performance. Coyle (1999) proposed that the power or velocity achievable at threshold is a more accurate measure of the endurance performance than the $\dot{V}O_2$max. Power output at this demarcation point is known as 'sustainable power', as an athlete is unlikely to fatigue quickly if exercise occurs below this threshold value. Continual exercise above the threshold will result in onset of fatigue due to the body utilising greater reserves of muscle glycogen to produce lactic acid (Jones & Carter, 2000). Thus the threshold occurs when one switches from performing mostly aerobic to mostly anaerobic work (Dumke, Brock, Helms, & Haff, 2006). Therefore, this measurement can be a better predictor of aerobic ability than maximal oxygen uptake (Atkinson et al., 2003; Loat & Rhodes, 1993) because $\dot{V}O_2$max also includes anaerobic work in its testing procedure. When using ventilatory markers to determine threshold, the two threshold values used include the VT_1 (first threshold value) and VT_2 (second threshold value) (Foster, Hoyos, Earnest, & Lucia, 2005). The intensity of exercise being performed is classified according to where it lies within these threshold limits and knowledge of these values is therefore important for both training and competition (Lucia, Hoyos, Perez, & Chicharro, 2000). Exercise performed below VT_1 is regarded as being easy, work between VT_1 and VT_2 is regarded as being moderate in difficulty, whereas anything above VT_2 is said to be high-intensity work (Foster et al., 2005). To date, studies which have measured thresholds in well-trained subjects performing concurrent training have shown no change in either the corresponding $\dot{V}O_2$ value or the power output value following both explosive (Paavolainen et al., 1999) and heavy resistance training (Bishop et al., 1999).

2.3.3 Economy of Motion and Efficiency

The activity being performed along with the testing protocol used usually determines whether a researcher will examine economy or efficiency. It is more common to calculate efficiency when running is being performed and to use economy as a measurement tool during cycling. Faria, Parker and Faria (2005b) explained that efficiency is calculated as a percentage of energy used in order to perform a bout of

work, whereas economy is the amount of oxygen uptake at a specific power output (Jones & Carter, 2000).

Resistance training has been shown to improve economy of motion in runners (Millet et al., 2002; Paavolainen et al., 1999; Turner et al., 2003) and cross-country skiers (Hoff et al., 1999). Bastiaans et al. found that delta (Δ) efficiency, which is the change in the relationship between energy and work, improved in trained cyclists following resistance training despite the fact that gross efficiency remained constant (Bastiaans et al., 2001). However, since it is known that the legs in cycling are almost completely responsible for the metabolic energy used (Bijker, de Groot, & Hollander, 2001) it follows that cycling at a higher power output would become relatively easier if the Δ efficiency or economy was improved. This suggests that resistance training may improve the ability of cyclists to work at higher power outputs (Faria et al., 2005b).

An interesting finding in the literature is that training to improve economy in well trained athletes requires a long period of time (Jones & Carter, 2000). Most studies which have measured this variable have found no change and Jones and Carter (2000) suggest that this is because the usual time frame for training studies of between 6 to 12 weeks is not long enough to elicit an improvement in economy.

2.3.4 Peak Power or Peak Velocity

Although peak power output or peak velocity obtained at the end of a progressive exercise test is not a physiological measurement per se, recent studies have discovered that it is a useful predictor of endurance performance (Atkinson et al., 2003; Hawley & Noakes, 1992; Noakes et al., 1990). Indeed, Atkinson et al. (2003) reported that the main difference found between elite and sub-elite riders is not their actual $\dot{V}O_2max$ but rather the power output that they are able to generate just prior to exhaustion on a progressive exercise test.

Noakes et al. (1990) claimed that the importance of this variable should not be ignored and suggested that it be reported in all studies which deal with the effects of training on performance. Their claim is well supported by several cycling studies which have shown that peak power output (PPO) was strongly correlated to performance in either a 30min time trial or a 20km time trial (Hawley & Noakes, 1992; McNaughton, Roberts, & Bentley, 2006).

2.4 Concurrent Training: A Brief Discussion on Adaptations and Performance Changes

Early strength gains achieved during a strength training program have been attributed to increases in neuromuscular function rather than initial muscular hypertrophy (Hickson et al., 1988; Tan, 1999). The neuromuscular status of the muscle is altered through resistance training by enabling either a greater muscle fibre recruitment (i.e. more active motor units) or by increasing the firing frequency of the motor units (i.e. creating larger forces by increasing the number of cross-bridge connections) (Docherty & Sporer, 2000). It should be expected that these same neuromuscular adaptations will occur when an untrained individual commences a program of concurrent resistance and endurance training. Trained athletes are less likely to incur noticeable changes described above since these are common only in early phases of training and athletes already have a well established base of strength. It is perhaps more surprising though that to date studies with well-trained cyclists have not reported whether neuromuscular changes occurred following resistance training (Bastiaans et al., 2001; Bishop et al., 1999). Despite being well-trained, cyclists typically do not include any form of traditional strength training into their training routines. It has been suggested by Hawley and Stepto (2001) that the immense volume of endurance training performed by well-trained cyclists causes the neuromuscular changes to already have occurred.

Concurrent endurance and resistance training programs conducted in runners and cross-country skiers has shown endurance performance enhancements. Paavolainen et al. (1999) examined the influence of a nine week explosive resistance training program on elite runners. They found that by dedicating a large portion (32%) of training time to explosive resistance exercise that athletes were able to improve (reduce) their time taken to run 5-km. Although there was only a small and non-significant reduction in time, when the results were compared with a control group who performed considerably less explosive resistance training (3% training time) there was a significant between-group difference. The authors attributed these improvements to increases in running economy and an enhanced stretch-shortening cycle capability (Paavolainen et al., 1999). Hoff et al. (2002) studied the effects of heavy resistance training on 19 male cross-country skiers. They found that after 8 weeks of training three times per week, the trained group improved strength, work economy and time to exhaustion. The authors suggested that the resistance training resulted in better economy by allowing slower recruitment of

muscle fibres as work was performed at a relatively lower load (Hoff et al., 2002). These results are partly due to an increase in the athletes' strength but are also due to the associated neuromuscular adaptations that occur during resistance training. (For further information regarding studies investigating adaptation and performance change in trained athletes and untrained individuals refer to Tables 1 and 2.)

2.5 Concurrent Strength and Endurance Training in Trained Cyclists

To date, only four published studies have examined the concurrent strength and endurance training using well-trained cyclists (Bastiaans et al., 2001; Bishop et al., 1999; Jackson et al., 2007; Paton & Hopkins, 2005) (Table 3). Bishop et al. (1999) incorporated heavy resistance training into the training regime of 21 well-trained female cyclists. A 12 week resistance training program was conducted twice per week over and above their regular endurance training. The weight training involved heavy squats (2-8-RM) to elicit maximum strength gains. Leg strength significantly improved following the training but there was no improvement in the lactate threshold, $\dot{V}O_2max$ or average power output over a one-hour time trial.

Recently, concurrent strength and endurance training has focussed on examining the effects of explosive type resisted movements on endurance performance (Bastiaans et al., 2001; Paavolainen et al., 1999; Paton & Hopkins, 2005). Bastiaans and colleagues (2001) performed a study, similar to that of Paavolainen et al. (1999) on runners, whereby a portion of the cyclists' endurance training (37%) was replaced by explosive resistance training. This ensured that the amount of work being performed by the cyclists was unchanged, thus ruling out the possible effects of overtraining. Sixteen male participants were involved in a nine week study in which eight subjects were required to perform four sets of 30 repetitions for three different explosive exercises (leg press, squat, and single-leg step up). The other eight subjects acted as a control group and did not undertake any resistance training. The average power output over a one-hour time trial increased significantly for the resistance trained group, but performance also increased in the control group. There was therefore no significant difference in the amount of improvement between the two groups. The most noticeable distinction between the two groups was that short-term performance (mean power measured over a 30 second period) increased slightly for the resistance group but decreased in the control group, thus creating a significant between-group difference. A similar trend occurred for delta efficiency (discussed above in section 2.3.3). Thus, the authors concluded that explosive resistance training can be substituted into the training

Table 1

Concurrent strength and endurance training in trained athletes

Study	Sport	Gender	Length of training	Type of training	Effect on strength	Effect on endurance
Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko (1999)	Running	Male	9 weeks	Sport-specific explosive strength training	Maximal isometric force increased for trained and decreased for non-trained	Improvement in 5-km run time. Improvement in running economy
Turner, Owings, & Schwane, (2003)	Running	Male and female	6/7 weeks	Plyometric training	No improvement in jumping tests	Improvement in running economy for trained group
Johnston, Quinn, Kertzer, & Vroman, (1997)	Running	Female	10 weeks	High resistance, low repetition for primary muscle exercises and low resistance, high repetition for secondary exercises	Large increases in 1-RM measured for various upper (24.4%) and lower (33.8%) body exercises	Improvement in running economy
Millet, Jaouen, Borrani, & Candau, (2002)	Running	Unspecified	14 weeks	High resistance, low repetition training	Significant increase in 1-RM strength for lower body exercises	Improvement in running economy
Hoff, Gran, & Helgerud, (2002)	Cross-country skiing	Male	8 weeks	Sport-specific high resistance, low repetition training	1-RM strength and force displayed higher increases in training group than in control group	Far greater improvement in time to exhaustion for training group (56%) than for control group (25%)
Hoff, Helgerud, & Wisløff, (1999)	Cross-country skiing	Female	9 weeks	Sport-specific high resistance, low repetition training	1-RM increased by 14.5% for strength trained group. Strength group also improved the rate of force development and peak force output at 1-RM	Improvement in economy of movement for double-poling action. Time to exhaustion increased significantly more for strength group than for control
Paavolainen, Häkkinen, & Rusko (1991)	Cross-country skiing	Male	6 weeks	Explosive strength training, heavy resistance training, and sprint training	Significant increase in height jumped during SJ and CMJ only for training group Increase in RFD during isometric leg extension testing	No effect on maximal aerobic capacity or thresholds

Table 2

Concurrent strength and endurance training in untrained subjects

Study	Gender	Length of training	Type of endurance training	Type of resistance training	Effect on strength	Effect on Endurance
McCarthy, Pozniak, & Agre, (2002)	Male	10 weeks	5 minute warm-up followed by 45 minutes of cycling at 70% heart rate reserve	High resistance, low repetition strength training	Increase in strength similar for strength group and concurrent group but not present in endurance group	Not tested
Häkkinen et al., (2003)	Male	21 weeks	Combination of basic training below aerobic threshold and interval training. Interval training added in week eight	Progressively higher resistance, lower repetitions for the leg extensor muscles and 8-15 reps per set for all other exercises	Both the strength and concurrent group increased their 1-RM similarly. RFD significantly improved only in strength group	Endurance variables such as VO_2max and power improved. However only concurrent group was tested for endurance
Hickson, Dvorak, Gorostiaga, Kurowski, & Foster, (1988)	Male and female	10 weeks	Maintaining previous training of cycling or running (intensities not specified)	High resistance, low repetition strength training	Strength increased for all exercised performed (30%)	Improvement in short-term performance (12%). Significant increase in cycling time to exhaustion and non-significant decrease in 10-km running time
Dudley & Djamil, (1985)	Male and female	7 weeks	Interval training on cycle ergometer at close to peak VO_2	Isokinetic strength training	Strength only improved at slowest contraction speeds for concurrent group compared to all but the fastest speed in strength group	Similar improvements in peak VO_2 increases for both endurance and concurrent groups

Table 3

Concurrent strength and endurance training in trained cyclists

Study	**Gender**	**Length of training**	**Type of training**	**Effect on strength**	**Effect on endurance**
Bastiaans, van Diemen, Veneberg, & Jeukendrup, (2001)	Male	9 weeks	Non-specific explosive strength training	Not reported	Short term performance and delta efficiency improved in comparison to untrained group
Bishop, Jenkins, Mackinnon, McEniery, & Carey, (1999)	Female	12 weeks	High resistance, low repetition squat training (up to 8-RM)	Very large increase (35.9%) in 1-RM for squat for training group	No changes for either trained or untrained group
Hawley & Burke, (1998) *	Unspecified	6 weeks	High resistance, low repetition leg exercises (6-8 RM)	Noticeable strength gains (~25%)	Increased time taken to complete 40-km time trial
Jackson, Hickey, & Reiser (2007)	Male and female	10 weeks	High res/low rep (4 sets of 4RM) training vs high rep/low res (2 sets of 20RM) training	Significant strength gains for both groups.	Improvement in economy and lactate thresholds but no better than a control group
Paton & Hopkins, (2005)	Male	4/5 weeks	Non-specific explosive resistance training combined with maximal intensity interval training	Not reported	Improvements in peak power and average power over a 1- and 4-km time trial

* not a published study.

regime of a well-trained cyclist without any negative effects and possibly some positive outcomes. They suggest that this form of training may be most useful to prevent decrements in endurance performance during periods of inclement weather, when outdoor cycle training can become difficult (Bastiaans et al., 2001).

Paton and Hopkins (2005) adopted a new approach to studying concurrent resistance and endurance training when they combined explosive resistance training with high-intensity sprint training to assess performance changes in cycling. In this study, subjects performed explosive single leg step-ups and five maximal 30 second sprints on the bike, with 30 seconds recovery between each sprint. This training was completed on 12 occasions over a four to five week period. Improvements were noticeable in average power and peak power over short durations (1- and 4-km). There was also an improvement in cycling economy as well as a small increase in the lactate-power relationship. The study design of combining explosive resistance training and high-intensity interval training makes it impossible to infer which intervention influenced the results found, and to what degree each type of training was responsible for the outcomes found (Paton & Hopkins, 2005).

The most recent study in this area assessed the effects of two different resistance training programs on cycling performance (Jackson et al., 2007). Twenty-three cyclists, both males and females, were assigned to one of three groups: a high-resistance/low-repetition group (n = 9), a high-repetition/low-resistance group (n = 9) and a control group (n = 5). After 10 weeks of training, three times per week, the researchers found that both resistance groups improved their strength. All three groups showed similar improvements in a delayed onset of lactate accumulation and improvement in cycling economy with none of the groups showing significant improvements in peak power during a progressive exercise test (Jackson et al., 2007). Similar to the study performed by Paton and Hopkins (2005), the cyclists in this study also performed hill climbing and interval training. These latest results suggest that resistance training, although not detrimental to performance, does not seem to provide any physiological benefit over pure cycle training in isolation.

Contrary to the published findings, an unpublished study cited by Hawley & Burke (1998) is the only indication that resistance training may hamper endurance performance in trained cyclists. This study found that after six weeks of heavy resistance training focussing exclusively on the legs (leg press, knee extensions, and knee flexion; three sets of 6-8- RM) strength increased by 25%, but endurance

performance decreased by 5%. Due to the lack of information it is unclear why the performance in this study decreased. One possible reason that has been suggested was that the athletes were pushed into a state of overtraining (Hawley & Burke, 1998).

The results of these five studies suggest that the addition of a resistance training program into the training regime of a cyclist does not appear to be beneficial. However since there are only few studies in this area, and 2 out of 4 of these studies have suggested that cycling power can increase for short durations following resistance training, more research in this area is warranted.

2.6 Limitations within the Previous Studies

A major limitation that arose which restricted the understanding of how resistance training affects endurance performance was that early studies did not actually perform concurrent training (Table 4). In early research subjects performed only resistance training and inferred how this type of training could enhance endurance capabilities (Marcinik et al., 1991). This method of research does provide some useful information for untrained populations but does not delve deep enough into the nature of concurrent training specifically for an endurance athlete, such as a cyclist. A significant limitation

Table 4

The effect of resistance training alone on endurance parameters in untrained subjects

Study	**Gender**	**Duration of study**	**Type of strength training**	**Effect on strength**	**Effect on endurance**
Hickson, Rosenkoetter, & Brown, (1980)	Male	10 weeks	High resistance, low repetition strength training	Large increases in 1-RM (at least 38%) for all exercises tested	Time to exhaustion increased following training
Marcinik, Potts, Schlabach, Will, Dawson, & Hurley, (1991)	Male	12 weeks	Moderate resistance weight training (8-20reps)	Significant gains in 1-RM strength for training group only	Improvement in cycling time to exhaustion at 75% VO_2 peak and concomitant increase in LT
Hurley, Seals, Ehsani, Cartier, Dalsky, Hagberg, & Holloszy, (1984)	Male	16 weeks	Single set, high resistance training (8-12reps) in a circuit type fashion	1-RM increased significantly for both upper (50%) and lower body (33%)	No change in VO_2max

within the current research on well-trained cyclists is that the tests used to assess endurance performance are not always well-matched to the competitive requirements of the sport. Of the six cycling papers reviewed, endurance performance was measured using six different methods, including time-to-exhaustion at a set intensity (Hickson et al., 1988), a 40km time trial (Hawley & Burke, 1998), the time taken to complete a specific amount of work that should be completed in one hour (Bastiaans et al., 2001), the average power output achieved during a one hour test (Bishop et al., 1999), the economy and lactate power response during a submaximal test (Paton & Hopkins, 2005) and the economy, lactate and power measured during a maximal oxygen uptake test (Jackson et al., 2007). All of these test have been used as predictors of endurance performance but none mimic the exact nature of road cycling, which generally requires competitors to cycle a set distance in the shortest amount of time; this is completed by altering the exercise intensity to include very hard and moderately-to-easy periods of work (Lucia et al., 2001; Schabort, Hawley, Hopkins, Mujika, & Noakes, 1998).

Generally our understanding into the effects of concurrent training with well-trained athletes is limited by the lack of research conducted in this area. One reason suggested for the low number of studies is the difficulty associated with changing the training regimes of elite athletes, especially when there is no guarantee that the modifications will be beneficial (Hawley et al., 1997). Moreover, the current body of research has not produced consistent results which are likely due to the methodological differences and possibly also due to the differences in the gender of subjects. Some studies have used only male participants (Bastiaans et al., 2001; Hawley & Burke, 1998; Paavolainen et al., 1999) some only female participants (Bell et al., 1993; Bishop et al., 1999) and those that have used both male and female subjects have not always differentiated the results (Hickson et al., 1988; Leveritt et al., 2003). Indeed, Bishop et al. (1999) have suggested that males and females may respond differently to concurrent strength and endurance training and therefore studies which include both males and females should discuss their findings accordingly. Another compounding factor within the research is that to date all studies with trained cyclists have employed only one type of resistance training, either heavy resistance training or explosive training. There is still a need to explore how these athletes would adapt to a mixed training protocol.

2.7 Summary and Conclusion

In summary most studies that have examined concurrent resistance and endurance training have found endurance performance either improved or remained stable. Only

one study reported that performance decreased and this was likely due to fatigue and/or overtraining by non-elite athletes. Of the measurements that have been used most often to predict aerobic performance, $\dot{V}O_2max$ and thresholds display little–to-no effect when resistance training was performed. Economy and efficiency are more likely to improve with resistance training in some athletes, suggesting that resistance training may improve performance through neuromuscular adaptations and possibly via improvements in anaerobic capacity.

Unfortunately there has been only limited research conducted with well-trained endurance cyclists. In these studies, endurance performance capability has been measured in several different ways and has revealed inconsistent findings between studies. It is therefore suggested that further research be conducted in this area to expand on the knowledge base using a test protocol that is more representative of competitive conditions.

3.0 METHODOLOGY

3.1 Subjects

Seventeen well-trained male cyclists/triathletes actively involved in competition for a minimum of 12 months participated in this study. Due to injury and illness, three participants withdrew prior to completion of the study. The remaining 14 subjects (mean (SD) age 31 (8) y; height 179.9 (8.6) cm; weight 77.4 (8.6) kg) were divided into a resistance training group (RT, n=7) and a control group (C, n=7). Allocation was based partially on availability to be involved in either group but was also controlled to ensure that physiological and performance baseline measures were as similar as possible. Participation was limited to individuals with no involvement in lower body resistance training for at least six months prior to commencement of the study. The study was approved by the Human Research Ethics Committee of Edith Cowan University and subjects provided written informed consent prior to participation.

3.2 Procedures

3.2.1 Overview

Baseline measurements of endurance, power, and strength were assessed at least twice before commencement of a six week intervention period. The last of the pre-test measurements was recorded no more than five days before the start of the training period. Post intervention testing was also conducted twice, with no more than 14 days elapsing between the last training session and the final testing date.

All testing and training was conducted at Edith Cowan University (Joondalup, Western Australia) in a specialised weight training room and exercise physiology laboratory. The members of the RT group commenced their training program under instruction not to compromise their normal endurance training regimen. Since endurance training was not strictly controlled, subjects were required to maintain a training diary (Appendix A) in which they recorded the time, distance, and intensity of each cycling session during the training period. Figure 1 outlines the entire experimental protocol.

The study consisted of four stages (familiarisation, pre-testing, training, and post-testing). During familiarisation, participants were provided with the opportunity to acquaint themselves with the equipment and procedures of the study. Following familiarisation sessions, pre-training baseline measurements were recorded. For two consecutive weeks at the beginning and end of the training period, subjects performed

the following tests over two consecutive days. On day 1, participants completed a one repetition maximum (1-RM) squat for assessment of maximal strength, a series of countermovement (CMJ) and squat (SJ) jumps and a 30 s repeat jump test for determination of sustainable power as well as a maximal oxygen uptake ($\dot{V}O_2max$) test. The following day (day 2) participants returned to the laboratory and performed a 30km time trial (TT_{30}) on a stationary cycle ergometer.

	Fam	Pre		Training						Post	
		Wk-1	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
Day1	A			P	P	P	P	P	P	A	A
Day2		A	A							TT_{30}	TT_{30}
Day3		TT_{30}	TT_{30}	H	H	H	H	H	H		
Day4											
Day5	TT_{30}			S	S	S	S	S	S		
Day6											
Day7											

A = VO_2max test; 1-RM test; Jump tests

TT_{30} = 30km time trial test

P = Resistance training workout – Power session

H = Resistance training workout – Hypertrophy session

S = Resistance training workout – Strength session

Figure 1 .Outline of the experimental protocol

3.2.2 Endurance Testing

3.2.3 $\dot{V}O_2max$ Test

A graded exercise test (GXT) was performed to determine maximal oxygen uptake and ventilatory thresholds for each subject. All cycling tests were performed on a Velotron cycle ergometer (Racermate, Seattle, WA, USA) with the accompanying Velotron Coaching Software. The test began with the subject cycling at 100 W and increased by 50 W every five minutes. Testing concluded when subjects reached volitional exhaustion (Hug, Laplaud, Savin, & Grelot, 2003b; S. B. Weston & Gabbett, 2001). A TrueOne® Gas Analyser (Parvomedics, Sandy, UT, USA) was used to measure concentrations and volumes of O_2 and CO_2 throughout the duration of the test. $\dot{V}O_2max$ was defined as the highest $\dot{V}O_2$ value recorded and averaged over a 30s period. Heart rate was recorded continuously throughout the test (Polar S610i, Polar Electro, Oy, Finland), while RPE was monitored using the Borg CR-10 scale at the end of each 5 min stage. The peak power output (PPO) was recorded as the power output of the last completed stage of the test plus the fraction of the workload during which fatigue was reached. This was determined using the following equation:

Equation 1: $PPO = W_{comp} + (W_{incomp} * (t_{comp}/5))$

PPO = peak power output; W_{comp} = power of the last completed workload; W_{incomp} = power of the workload at completion; t_{comp} = time the last workload was maintained for before exhaustion

Ventilatory thresholds were determined according to established methods (Hug, Faucher, Kipson, & Jammes, 2003a; Lucia et al., 2000). The first threshold (VT_1) was determined by an increase in the $VE/\dot{V}O_2$ ratio without a concomitant increase in the VE/VCO_2 ratio, while the second threshold (VT_2) was defined as the point where there was a simultaneous increase in $VE/\dot{V}O_2$ and VE/VCO_2. All thresholds were determined independently by two qualified exercise scientists. If there was a discrepancy, a third exercise scientist was used to determine the threshold points.

3.2.4 30km Time Trial

A 30km stochastic time trial test was used to assess both sprint and endurance performance. The time trial, a modified version of the 100km time trial designed by

Schabort and colleagues (Schabort et al., 1998; St Clair Gibson, Schabort, & Noakes, 2001), included sprint sections which were interspersed within the 30km test (Figure 2). There were three 250m sprints performed at 4, 14, and 24 km as well as three 1km sprints performed at 9, 19, and 29 km. The high-intensity all out sprints allowed for analysis of sprint performances within an endurance time trial.

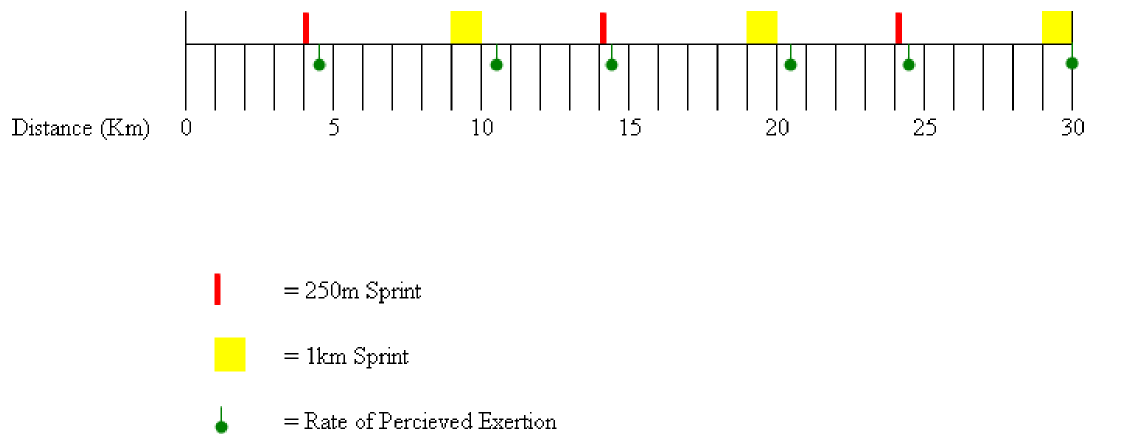

Figure 2. The time trial protocol

A standardised 10 min warm up was performed prior to each time trial. The warm up consisted of three different intensities determined using the PPO recorded on the preceding day's $\dot{V}O_2max$ test. The intensities were 25% PPO for 3 minutes, 60% for 5 minutes, and 80% for 2 minutes. During the time trial, heart rate, average and instantaneous (accurate to 1 s) speed, power and cadence as well as distance and elapsed time were continuously recorded, while rating perceived exertion (RPE) was measured after each sprint (Figure 2). RPE was measured according to the CR-10 scale (Foster et al., 2001).

Apart from the distance completed, subjects were blinded to all other forms of external feedback during the time trials. Knowledge of the distance completed allowed subjects to be aware of when they were approaching each sprint section. However, verbal reminders were given to alert the rider of each upcoming sprint. During the sprint, athletes were encouraged to perform maximal efforts throughout. Power output was verified using a scientific version SRM (Shoberer Rad Mebtechnik, Germany). The SRM power meter is regarded as the most accurate measurement device for power determination during cycling and calculates the power produced at the bottom bracket

by measuring the torque applied to a cycle crank and its cadence (Vogt et al., 2006). Torque is determined via a series of in-parallel strain gauges that measure the amount of deformation of the metal making up the crank, while the cadence is detected using a “reed contact” technique. Analysis of the sprinting sections was performed using data collected via the SRM power meter. Peak power output was determined as the highest power averaged and recorded each second.

The Velotron cycle ergometer was set up specifically to replicate the settings on each individual’s own road bike. These settings were recorded for each subject during their first visit to the laboratory and replicated for all subsequent tests. Stable environmental conditions during the tests were maintained in a climate chamber set at 16˚C with a relative humidity of 40%. Furthermore a large fan was positioned to face each cyclist front on and provided head-winds similar to those experienced during outdoor cycling (Saunders, Dugas, Tucker, Lambert, & Noakes, 2005). Water was permitted *ad libitum* during the time trials.

3.2.5 Strength and Power

3.2.5.1 Strength

The 1-RM squat was used to assess lower limb muscular strength. According to the procedures outlined by Baechle et al. (2000), the 1-RM was determined as the maximal amount that a participant could successfully lift only once. Prior to the 1-RM, a warm-up consisting of an initial set of six lifts with a low resistance was performed before increasing the weight for one set of three lifts (Faigenbaum, Milliken, & Westcott, 2003). After a self-selected rest period, subjects began to complete their one repetition sets. The first lift was performed at an estimated resistance that would allow the completion of only one lift. Following each successful lift, additional resistance was added until the subject’s 1-RM was determined. The 1-RM was always completed within five attempts in accordance with previous recommendations (McBride, Triplett-McBride, Davie, Abernethy, & Newton, 2003).

3.2.5.2 Power

While cycling power output was assessed during the $\dot{V}O_2max$ test and time trial, vertical leg power was assessed during a series of 30 s repeat jumping test (RJ30). Jump tests were performed on a Kistler™ force plate (Kistler Instruments, NY). The RJ30 was

performed once and analysed for the number of jumps completed, average power, and fatigue index (average power of the last 5 jumps / average power of the first 5 jumps) (Sands et al., 2004). Subjects were instructed to jump for maximal height during each jump of the RJ30 and were also instructed to include a small countermovement phase after each jump. During each test the subject's hands were placed on their hips in order to reduce the influence of the upper body on lower limb power (Canavan & Vescovi, 2004).

3.2.5.3 Leg girth

Thigh girth was measured at 50% of Vastus Lateralis in order to determine whether there was an increase in muscle mass in the lower limb. Muscle length was measured based on previous methods (Blazevich, Gill, Bronks, & Newton, 2003). Briefly the Vastus Lateralis was determined to run from the centre of the greater trochanter to the joint cleft at the lateral condyle of the femur. The measurement for leg girth at this muscle length provided a high degree of reliability (CV = 1.2; ICC = 0.96).

3.2.6 Training Program

Resistance training was performed three times per week using an undulating periodization model. Each session had its own particular emphasis, and this determined the intensity of the training. These three types of training sessions were classified as strength, power, and hypertrophy sessions (Table 5) (Kraemer & Ratamess, 2004). A minimum of 24 h separated each resistance training session. Table 5 illustrates all the exercises performed for each of the three different sessions. A novel idea incorporated into the current resistance exercise was the implementation of single leg exercise to provide added neuromuscular specificity to the training program for the cyclists, as cycling is mainly a unilateral performance task. Progression in intensity was adjusted by the resistance applied during exercising and by altering the number of sets and number of repetitions performed. Power exercises were performed for 3 sets (6 repetitions), hypertrophy exercises were performed for 3 sets (8 - 12 repetitions), and strength exercises were performed for 4 sets (5 repetitions). Recovery between all sets was set at 2 min regardless of the training being undertaken. All sessions began with a 5 min warm-up performed on a cycle ergometer (Monark, 818E, Sweden) at a self-selected pace. Intensity of the resistance training was monitored by a trainer who used both

visual cues and subjective feedback to ensure that the subjects were training to the specifications of the program and to determine when to change the resistance of each exercise. Subjective feedback was gathered through the use of the RPE scale (Appendix B). This was collected at the end of each set (Day, McGuigan, Bruce, & Foster., 2004; Foster et al., 2001) and at the conclusion of the entire session (Singh, Foster, Tod, & McGuigan, 2007) (Appendix C, D, & E).

Additional resistance was added at the discretion of the investigators throughout the training period to ensure that each session used resistance that best suited the objective of the training. Subjects were expected to attend all training sessions but compliance was set at 94% (17 of 18 sessions) for subjects to remain in the study.

Table 5
Exercises and order of performance for each of the type of resistance training sessions

Power	**Hypertrophy**	**Strength**
Jump squats	Single-leg leg press	Lunges
Single-leg jump squat	Knee extension	Squats
Clean grip deadlift	Knee flexion	Straight-leg deadlift
Single-leg calf raise	Standing calf raises	Seated calf raises
Back extension	Abdominal crunches	Inclined crunches

3.2.7 Reliability of the Cycling Tests

Initial data was collected from a sample of 15 cyclists that completed the testing. All 15 participants' data were used to assess the reliability of the time taken to complete the 30kmTT. Only 14 subjects had sufficient information to analyse the sprint power produced via the SRM and via the Velotron.

Reliability of the tests post intervention was measured for the entire group. Eleven of the 14 subjects were used to determine the reliability of the VO_2max test following the training intervention. Two subjects only completed one post test session and a further subject performed one of his tests with incorrect calibration procedures.

Twelve subjects completed both TT tests but SRM data was unavailable for one of the test sessions. Therefore reliability of sprint data using SRM was performed using data from 11 participants'.

3.4 Statistical Analysis

A one-way ANOVA was used to determine if there were any significant differences between the two groups. A two-way (group by time) analysis of variance (ANOVA) delineated significant differences between the dependant variables of strength and endurance performance in the control vs. the resistance training group before and after the training intervention. To assess the influence of the resistance training program, a paired *t*-test was performed to examine differences between the change in strength over time between groups. Cohen's effect sizes (ES) were used to determine if there was a change between the mean of the variables over time. Reliability was determined using the intraclass correlation coefficient (ICC) and the coefficient of variation (CV's). Pearson product moment correlations examined relationships between variables. Significance was set at an alpha level of 0.05 and data are presented as means and standard deviations.

4.0 RESULTS

4.1 Subject Characteristics

The characteristics of the final 14 subjects (n = 7 per group) are displayed in Table 6. While the control group was significantly older than the resistance training group, the groups were similar in terms of their physical and physiological variables.

Table 6. Subject characteristics presented as mean (SD).

	RT	**C**
Age (y)	25 (4)	37 (7) *
Height (cm)	180.5 (9.6)	179.2 (8.0)
Weight (kg)	78.6 (9.4)	76.2 (8.3)
Maximal oxygen uptake (ml/kg/min)	62.4 (5.4)	63.1 (1.8)
1 Repetition Max -Squat (kg)	109 (18)	105 (20)

*significantly different from RT group ($p < 0.05$)

The average training distance and average time completed by the groups before and during the training period are displayed in Table 7. No significant differences were found between the groups for changes in training distance or for the time spent cycling. The amount of time that the RT group spent cycling decreased slightly from their initial level whereas the amount of riding time increased for the control group. This difference resulted in an ES of 0.5 (Hopkins, 2003) which suggests that there was a moderate increase in the amount of time spent cycling by the C group compared to the RT group. Training time for the RT group does not include the time spent performing resistance training. This was approximately 180 min / week.

Table 7. Time and distance reported by the subjects during cycle training.

	RT		C	
	Pre	During	Pre	During
Average Distance (km)	279 (84)	274 (56)	265 (81)	278 (34)
Average Time (min)	542 (102)	526 (85)	568 (137)	613 (78)

4.2 Training Study Results

<u>Effect of concurrent training on overall TT performance</u>

No significant differences were found for either the RT group or the C group in the time taken to complete the 30kmTT or in the average power output achieved during the TT after the training intervention. The mean (SD) performance criteria are displayed

in Table 8. Closer inspection revealed that the C group marginally increased their average power output (+ 2 W) and therefore improved their time to complete the time trial (- 10 s).

Table 8. Time to completion (TTC) and average power output during the 30kmTT

	RT pre	RT post	C pre	C post
TTC (s)	2823 (142)	2825 (104)	2851 (125)	2841 (119)
Power (Watts)	295 (43)	295 (31)	285 (33)	287 (31)

RT – resistance training group, C – control group

Effect on average and peak power output during 250m and 1km sprint stages

The average (SD) power output for the 250m sprints is displayed in Figure 3. As illustrated there was no significant difference in the power output achieved at each sprint for any of the four conditions. There was also no difference between pre and post measurements for either of the groups at any of the three sprints.

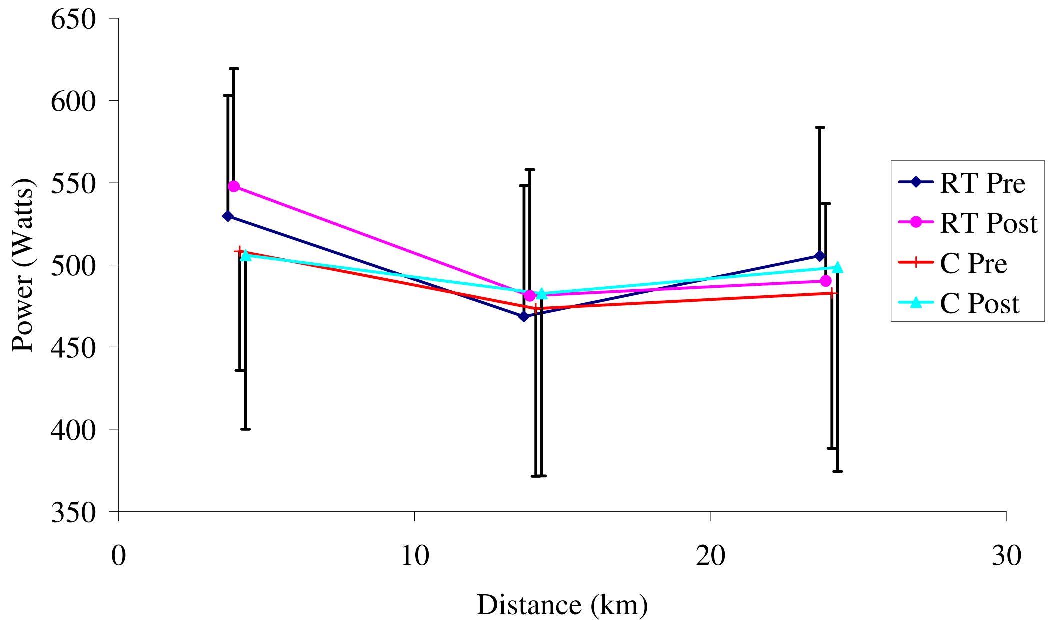

Figure 3. Average power output of the 250m sprints for the resistance training (RT) and control (C) groups measured using an SRM pre vs. post training.

The change in the average power output during the sprints from pre to post training is presented in Table 9. This result is presented as a percentage of the power

output. The change was not significant for either group and only small effect sizes were found (0.0 – 0.3).

Table 9. Changes in average power output pre to post intervention for both the resistance training (RT) and control (C) group.

		4km	14km	24km
RT	% change	4 (7)	3 (9)	-2 (10)
	ES	0.3	0.2	-0.2
C	% Change	-1 (10)	2 (8)	3 (9)
	ES	-0.0	0.1	0.2

The change in average power output between each 1km sprint and over the course of the intervention for both groups is illustrated graphically in Figure 4. There were no significant differences found between groups for any of the sprints or within groups for changes over time.

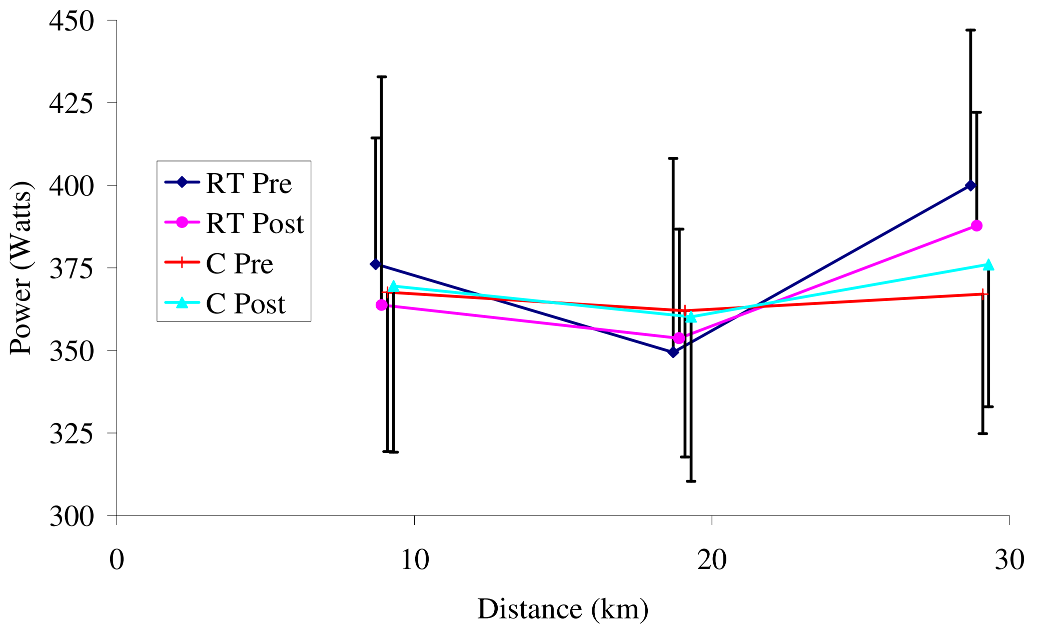

Figure 4. Average power output of the 1km sprints for the resistance training (RT) and control (C) groups measured using an SRM pre vs. post training.

The change in power output (%) during the 1km sprints from pre to post training for each group is reported in Table 10. The change was not significant for either group and only small effect sizes were found (0.1 – 0.3). The RT group decreased their

performance in 2 of the 3 sprints whereas the C group improved in one sprint, decreased in one and remained constant in the other.

Table 10. Changes in average power output pre to post intervention for both the resistance training (RT) and control (C) group

		9km	19km	29km
RT	% change	-4 (14)	3 (15)	-3 (5)
	ES	-0.3	0.1	-0.3
C	% Change	0 (4)	-1 (4)	3 (8)
	ES	0.0	-0.1	0.2

There were no significant differences between pre and post training peak power output for either of the groups during all three sprints (Figure 5). There was also no difference in the peak power output attained at each of the sprints for any of the conditions measured.

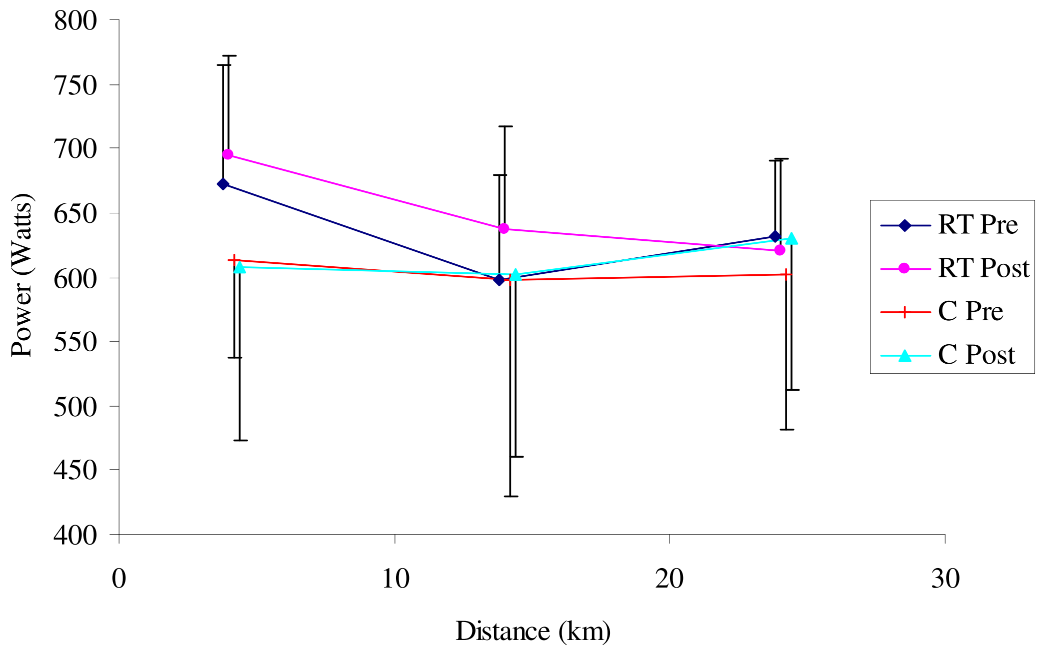

Figure 5. Peak power output of the 250m sprints for the resistance training (RT) and control (C) groups measured using an SRM pre vs. post training.

The change in peak power output during the 250m sprints from pre testing to post training for both groups is recorded in Table 11. This result was measured as a

percentage of the power. The change was not significant for either group and only trivial effect sizes were found. The RT group increased their peak power output in 2 of the 3 sprints with the C group displaying a similar response.

Table 11. Changes in Peak power output pre to post intervention for both the resistance training (RT) and control (C) group

		4km	14km	24km
RT	% change	3 (14)	6 (15)	-3 (9)
	ES	0.2	0.4	-0.3
C	% Change	-2 (17)	3 (11)	7 (12)
	ES	-0.1	0.1	0.3

Peak power output values for the 1km sprints are represented in Figure 6. There was no significant difference found for the change in peak power output pre to post training for either group. There was also no significant difference in the peak power output reached at any of the three distances for any of the four measurements.

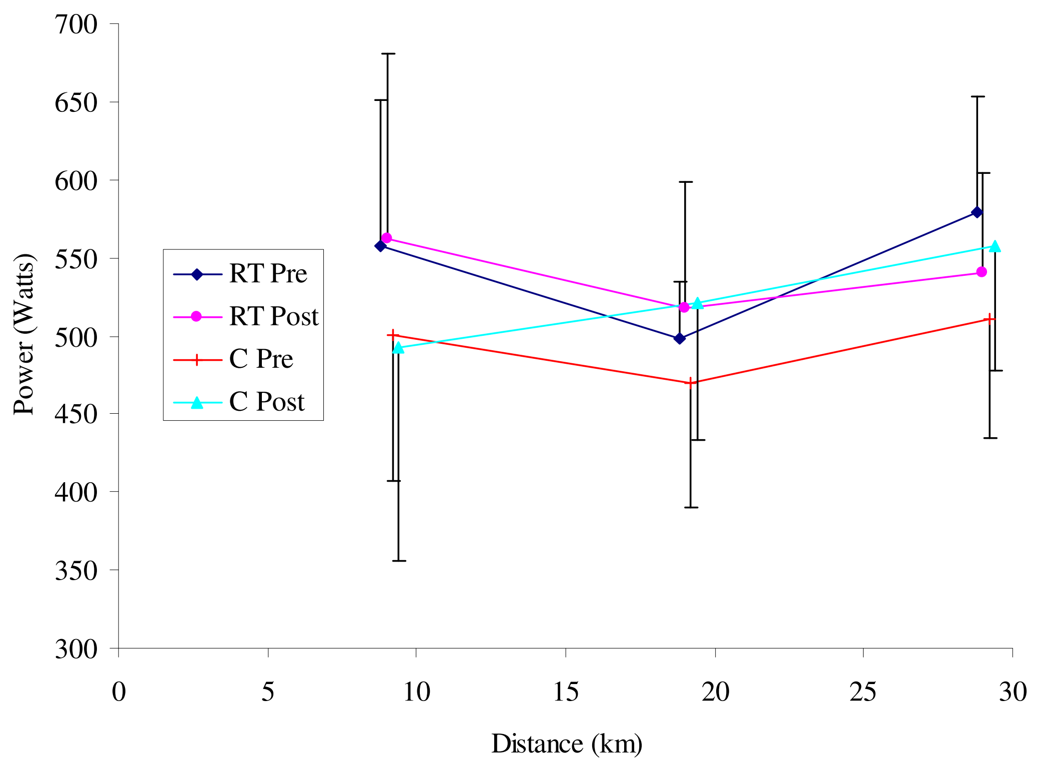

Figure 6. Peak power output of the 1km sprints for the resistance training (RT) and control (C) groups measured using an SRM pre vs. post training.

The data presented in Table 12 reveals the change in the peak power output during the 1km sprints from pre testing to post training for both groups. This result was measured as a percentage of the power. The change was not significant for either group but moderate to large effect sizes were found for three of the conditions (Hopkins, 2003). The RT group reduced their peak power output in the final sprint whereas the C group improved their peak power output in the same sprint. The ES analysis showed that the change in peak power output was moderate. The C group also showed a moderate to large change in the amount that the peak power output increased during the 1km sprint commencing at the 19km point in the TT. Other effect sizes calculations resulted in no change or only small changes. Overall the peak power output of the RT group increased in one sprint and declined in two, whilst the peak power output of the C group increased substantially in 2 of the 3 sprints and was unchanged in the third.

Table 12. Changes in peak power output pre to post intervention for both the resistance training (RT) and control (C) group

		9km	19km	29km
RT	% change	-2 (17)	2 (18)	-5 (7)
	ES	-0.1	0.2	-0.4
C	% Change	-1 (32)	13 (27)	11 (27)
	ES	0.0	0.8	0.5

The ES for the change in power output over time between the two groups are reported in Table 13. There were four occasions where the change appeared to suggest a common trend, despite not being statistically significant. In each of these four cases the power output value of the RT group decreased whereas the power output value of the C group improved. This resulted in a negative ES which suggests that the training may have been detrimental in these cases.

Table 13. Effect sizes for changes in the mean power output pre vs post for RT and C group

	250m Sprints			1km Sprints	
	AP	PP		AP	PP
4	0.3	0.3	9	-0.3	0.1
14	0.0	0.2	19	0.1	**-0.9**
24	-0.4	**-0.6**	29	**-0.5**	**-0.9**

AP = average power; PP = peak power

Effect on strength, power and physical characteristics

Strength assessed via a 1-RM squat increased following the 6-wk training period in the RT and C group from 109 (18) kg to 137 (21) kg and 105 (20) kg to 113 (22) kg respectively. Both groups significantly increased strength over time, and no significant different was found between the groups ($p = 0.2$) (Figure 7).

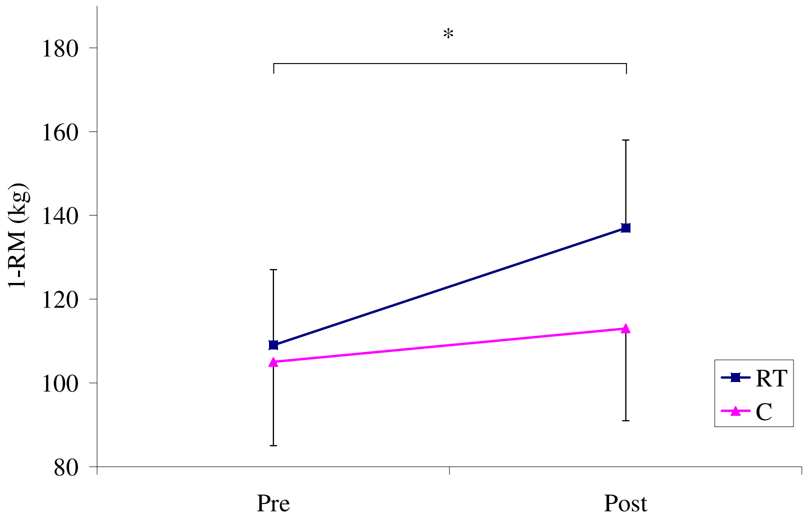

Figure 7. Change in 1 repetition maximum (1-RM) squat strength for the resistance training group (RT) and control group (C) pre vs. post training.

* significant difference over time $p < 0.05$

Further analysis revealed that the 1-RM increased by a mean value of 28 (9) kg in the RT group and only 8 (9) kg in the control group. This change was statistically significant between groups (Figure 8) and is complemented by an ES of 1.1 (Hopkins, 2003). This effect size suggests that there was a moderate to large difference for the increase in 1-RM for the RT group compared to the C group.

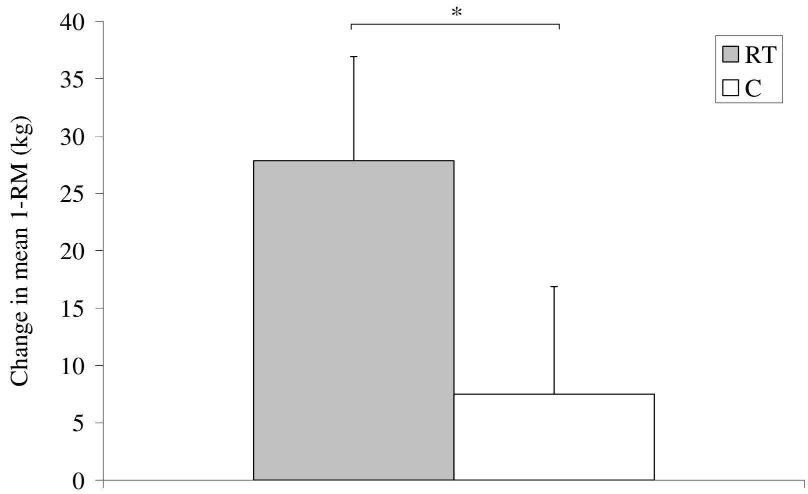

Figure 8. Change in the mean of the 1-RM squat from pre- to post measurement.

* significant difference between the change in the mean between groups p < .001

RT – resistance training group, C – control group

Power assessed via the RJ30 test yielded 3 different results: the total number of jumps (# jumps), the average power of the jumps (AP jump) and the fatigue index (FI). The mean (SD) values have been reported in Table 14. There were no differences pre to post training for the RT and C group for # jumps or the AP during the RJ30 test. FI was significantly different between groups ($p < 0.05$) and approached significance when compared between time periods ($p = 0.09$) (Figure 9). An ES of 0.5 was also found using Cohen's effect size for a change in the mean (Hopkins, 2003). This effect size suggests that the increase in FI for the RT group was moderate to strong.

Table 14. Characteristics of the performance variables from the RJ30

	RT pre	RT post	C pre	C post
# jumps	29 (6)	28 (7)	32 (7)	32 (8)
AP jump	22 (2)	24 (3)	24 (7)	26 (7)
FI	78 (6)	88 (10)	90 (12)	95 (13)

RT – resistance training group, C – control group, AP – average power, FI – fatigue index,

RJ30 – 30 second repeat jump test

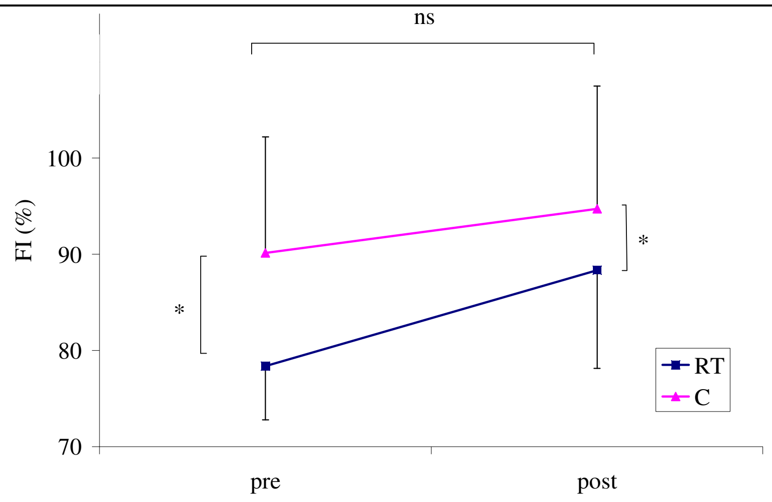

Figure 9. Change in the fatigue index (FI) over time for the resistance training (RT) and control (C) group.

* Significant difference $p < 0.05$ between groups at both time points

ns no significant difference over time

The physical characteristics of body mass and leg girth also showed no change over time and no difference between the groups. The mean (SD) are reported in Table 15.

Table 15. Body mass and leg girth

	RT pre	RT post	C pre	C post
Girth	56.4 (2.6)	56.4 (2.6)	55.4 (3.6)	55.4 (4.2)
Weight	78.6 (9.4)	78.5 (9.2)	76.2 (8.3)	76.2 (8.6)

RT – resistance training group, C – control group

Effect on maximal oxygen uptake (VO_2max), peak power output (PPO), and ventilatory thresholds (VT_1 and VT_2) during a maximal aerobic test

The RT group and C group produced similar results for their maximal oxygen uptake (VO_2max) at both the pre-training assessment and following the training intervention. The RT group marginally decreased their oxygen uptake from the pre to post testing. A similar trend was found for the control group (Table 16).

Peak power output assessed during the maximal oxygen uptake test did not change significantly during the study, either between groups or over time. There was a trend for

a slight reduction in peak power output for the RT group. The control group likewise reduced their peak power output from initial testing to post testing (Table 16).

The ventilatory threshold (VT) variables are presented as a relative VO_2 value (Relative), as a percentage of the final VO_2max value from that test (% max), and as the absolute power values (Watts). The VT_1 and VT_2 demarcation points are reported in Table 16.

Table 16. Maximal oxygen uptake (VO_2max), peak power output (PPO) during the VO_2max test, and ventilatory threshold values reported as a relative value of VO_2 (Relative), a percentage of the final VO_2max (% max) and as absolute power at thresholds.

		RT pre	RT post	C pre	C post
VO_2max	($ml.kg^{-1}.min^{-1}$)	62.4 (5.4)	62.3 (3.2)	63.1 (1.8)	62.5 (2.7)
PPO	Watts	361 (36)	355 (27)	352 (39)	348 (37)
VT_1	Relative ($ml.kg^{-1}.min^{-1}$)	37.4 (4.4)	39.5 (2.9)	39.0 (5.3)	41.0 (2.2)
	% max	56 (8)	62 (7)*	55 (5)	61 (3)*
	Watts	197 (32)	219 (34)	191 (18)	211 (27)
VT_2	Relative ($ml.kg^{-1}.min^{-1}$)	53.2 (3.6)	52.7 (3.9)	51.4 (4.4)	52.1 (1.9)
	% max	85 (7)	84 (4)	81 (5)	82 (2)
	Watts	305 (39)	297 (30)	281 (22)	285 (34)

RT – resistance training group, C – control group

* significant difference to pre test ($p < 0.05$)

There was no difference for VT_1 variables between the RT and C groups. There was however a trend for a delayed onset of VT_1 following the training intervention ($p < 0.05$). However this occurred in both groups. A significant change in VT_1 in both groups was found when data was presented as a relative percentage of VO_2max ($p = 0.02$), however the change over time was similar for both groups. No significant difference was found for the measurement of VT_2 between the RT and C groups either before or after the training intervention.

4.3 Reliability of measurements during cycling tests

The mean (SD) results achieved for trial 1 and trial 2 were used to measure the reliability of the cycling tests prior to a training intervention. The reliability was then compared to the same measurements recorded from two consecutive trials following a training intervention. Table 17 reports the mean (SD) of the trials, CV, ICC and the typical error associated with each test (Hopkins, 2000). There was no difference in the reliability of the tests whether they proceeded or followed a training intervention.

Table 17. Reliability of results for the cycling tests prior to and following a training intervention

	Trial	Mean (SD)		CV		ICC		Typical Error	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
VO_2max ($ml.kg^{-1}.min^{-1}$)	1	62.3 (3.7)	61.5 (3.4)	2.0	1.9	0.91	0.87	1.2	1.2
	2	62.0 (4.3)	62.3 (2.9)						
VO_2 PPO (Watts)	1	354 (37)	346 (34)	2.5	1.5	0.95	0.98	8.3	5.0
	2	352 (39)	352 (34)						
Sprints Vel (Watts)	1	394 (50)	394 (52)	2.9	2.7	0.95	0.96	11	10
	2	394 (48)	405 (49)						
Sprints SRM (Watts)	1	394 (51)	394 (49)	3.2	3.3	0.95	0.93	12	13
	2	393 (49)	403 (49)						
TT 30km (seconds)	1	2847 (167)	2861 (144)	1.3	1.3	0.93	0.91	41	38
	2	2823 (136)	2832 (106)						
TT 30km (Watts)	1	289 (42)	286 (38)	3.1	3.5	0.96	0.92	7.6	9.7
	2	293 (38)	291 (28)						

5.0 DISCUSSION

The primary purpose of this study was to supplement an endurance trained cyclists' regular training workload with a six-week resistance training program and to examine its effect on endurance performance, sprint performance, strength and physiological changes. A secondary purpose of this study was to examine the reliability of ergometer cycling tests prior to and after a brief training intervention.

5.1 Endurance performance

The main finding of this study was that the concurrent endurance and resistance training group did not enhance their endurance performance. This in agreement with previous studies that have assessed the effect of concurrent resistance and endurance training on trained cyclists (Bishop et al., 1999; Jackson et al., 2007) and non-cyclists (Paavolainen et al., 1991). The two primary markers that were used in this study to determine endurance performance, the VO_2max and the 30km time trial performance, did not differ for either group before or after a six week period of resistance training or a control period. A third marker of endurance that was measured was the ventilatory thresholds (VT_1 and VT_2).

The most important finding from the study was that the overall time taken to complete the 30kmTT and the average power output achieved during the TT did not differ after training for either group. The 30kmTT should be considered as the main determinant of performance improvement since the present study was interested in deciphering whether resistance training could benefit overall endurance cycling. This type of cycling is known to be characterised by moderate intensity work periods interspersed with a few high-intensity maximal work efforts (Atkinson et al., 2003).

Some studies have found concurrent training to improve endurance performance, both with trained cyclists (Paton & Hopkins, 2005) and other trained athletes (Hoff et al., 1999; Johnston et al., 1997; Millet et al., 2002; Paavolainen et al., 1999). In the case of Paton and Hopkins (2005), their finding that 1- and 4-km time trial performance increased could have also been a result of high intensity interval training being employed in addition to resistance training. It has been well documented that the changes that occurred in the study by Paton and Hopkins (2005) are consistent with changes that would have occurred had they performed the same training without the use of resistance training (Laursen & Jenkins, 2002; Laursen, Shing, Peake, Coombes, &

Jenkins, 2005b; Stepto et al., 1999). Many of the other studies that have reported an improvement in endurance following concurrent training often do not include an actual performance test and only report aerobic markers such as $\dot{V}O_2max$, lactate or ventilatory thresholds, and work economy or efficiency (Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003; Hickson et al., 1988; Johnston et al., 1997). Whilst these markers are all useful predictors of success in endurance events, economy, efficiency and thresholds, in particular the first threshold, are submaximal performance criteria and improvements at those levels will not necessarily translate to improvement in a maximal effort endurance event. An improvement in $\dot{V}O_2max$ or second threshold (VT_2) is more likely to coincide with improved endurance performance since these markers reflect measurements at very high intensities (Atkinson et al., 2003). The current study found that VT_1 and VT_2 occurred at approximately 61% and 83% of $\dot{V}O_2max$. This is similar to Hug et al. (2003b) who found VT_1 and VT_2 occurred at 62 and 89% of maximal power output in a group of elite cyclists performing a graded exercise test (100W + 26W.min^{-1}). From this information it could be suggested that the 30kmTT performance may have improved had the concurrent training been successful in improving either the power output or percentage VO_2 at which VT_2 occurred, however this was not the case.

A further hypothesis of this study was that the training would increase the power output at ventilatory thresholds, without changes in maximal oxygen consumption. The power output at VT_1 was found to increase in both groups (ES = 0.7 and 0.6 for C and RT respectively). However no difference was noted in the power at which VT_2 was produced. The increase in power at VT_1 is likely due to the continued cycling training that was being performed. The lack of prescribed high intensity interval training and hill climbing performed during the study suggests that the cycling training on its own was not likely to influence VT_2. Power at threshold is likely to be a more important measurement for a maximal time trial performance as opposed to submaximal economy. This is because thresholds have been shown to correlate to maximal time trial performance (Amann, Subudhi, & Foster, 2006), whereas economy is more a measure of submaximal performance (Faria, Parker, & Faria, 2005a).

The $\dot{V}O_2max$ of the cyclists in the current study remained relatively unchanged from pre- to post training. This is similar to Bishop et al. (1999) who used purely high resistance, low repetition resistance training and found that the VO_2max of their female cyclists did not change pre to post training (48.2 – 48.4 ml.kg^{-1}.min^{-1} respectively). Bishop et al. (1999) also employed an endurance time trial and found that the average

power produced over one hour did not change significantly for either the trained or control group. This relationship enhances the thought that the two most important markers of maximal endurance performance with the exception of an actual performance test that replicates the nature of the athletic activity are the $\dot{V}O_2$max and second ventilatory threshold.

5.2 Peak power output during a graded exercise test

A further measurement that has gained popularity in determining endurance performance is the maximal power output or speed achieved at the conclusion of a maximal aerobic capacity test. This value has been shown to provide a high correlation with performance in running (Noakes et al., 1990) and cycling (Hawley & Noakes, 1992) time trials. Although this measurement is not strictly a physiological measurement such as VO_2max or the lactate and ventilatory thresholds, Noakes et al. (1990) have stated that it is especially important to consider this variable when analysing results from a maximal graded exercise test. In the current study, the PPO for both groups remained constant from pre- to post-training measurements. The value of PPO reported for the groups of ~350 watts is similar to that reported in a study by Bastiaans et al. (2001) (~330 watts) despite distinct differences in the methodologies used for testing. However, the PPO of the trained cyclists in the study by Paton and Hopkins (2005) greatly exceeded that of the cyclists in the current study. Atkinson and colleagues (2003) suggest that this may be as a result of the duration of the stages within each test. In the current study each workload was maintained for 5 min whereas in the study by Paton and Hopkins (2005) the intensity was increased each minute.

5.3 Sprinting performance

A somewhat novel inclusion in the current 30kmTT of the present study was the designated sprinting sections. The only previous studies that have included sprinting within a cycling TT were performed over a distance of 100km (Schabort et al., 1998; St Clair Gibson et al., 2001). It was hypothesised that RT would have led to improvements in sprint performance by increasing the peak power output and the peak sustainable power (average power output over the duration of the sprint). This however was not the case. In fact it was found that both the peak power output and average power remained relatively stable regardless of whether resistance training was performed. Conversely,

all differences that were found indicated that the resistance training was verging on becoming detrimental to sprinting performance as indicated in Table 17, with the negative ES of 0.5 or more (i.e. relative to the power output of the RT group, the C group increased their power output). This was found even though resistance training in the current study included six sessions (out of 18) that were focussed on the development of power. Indeed, it is well known that resistance training results in physical and physiological adaptations such as increased cross-sectional area of the muscle, neuromuscular changes, and increases in contractile muscle proteins (Coffey et al., 2006; Docherty & Sporer, 2000) that assist in the development of anaerobic power. In isolation it would be expected that this type of training would result in an increased peak and average power produced over the course of a short sprint since there would be a considerable anaerobic energy component required in a sprint. Furthermore, it has been reported that in order for cyclists to succeed in time trial events, a rider must train both their aerobic and anaerobic energy systems (Hawley & Stepto, 2001). Previous studies have shown that Wingate power (Balabinis et al., 2003; Kraemer et al., 2000; Leveritt et al., 2003) and short term cycling performance (Hickson et al., 1988) have increased after individuals performed a resistance training program ranging from 6 weeks to 9 months. Interestingly, these previous studies have used a separate test to determine maximal power output on the bike whereas short term performance in the current study was assessed during sprinting that was integrated into the overall 30kmTT.

Bastiaans et al. (2001) found that the average power output of an all-out 30 second ergometer test (short term power) remained stable for a group that performed resistance training whereas over a nine week period the short tem power of the control group decreased. This value could be similar to that of a short sprint or surge of pace. The research by Batsiaans and colleagues (2001) would appear to suggest that explosive resistance training could have been useful to improve, or at least reduce performance decrements in sprinting within the 30kmTT. This was not the case. A possible reason for this may be due to the fact that different methods of power training were employed (low vs. high repetitions). Furthermore, Bastiaans et al. (2001) reduced the amount of endurance training in accordance with the amount of RT performed. This ensured an equivalent amount of work was performed between groups and avoided subject overtraining.

A more likely reason for the lack of improvement in sprinting performance found following RT is the fact that the current study investigated the maximal power of a sprint during a closed loop time-trial test. Since subjects were instructed to complete the overall 30kmTT in the shortest possible time as well as give maximal efforts during the sprinting sections, it is likely that pacing strategies may have impacted the sprinting results. Well-trained cyclists would be well aware that performing a maximal effort during a 1-km sprint would lead to a significant amount of recovery time, leading to a detriment in overall TT performance. Secondly, previous research has also suggested that a more constant pacing strategy before a time trial produces better results during the subsequent time trial (Palmer, Noakes, & Hawley, 1997) and the experienced cyclists in this study may have been aware that extremely variable pacing may have been detrimental to their overall performance. It could therefore be suggested that a limitation of the current study was the inability to assess a true peak power output and peak sustainable power during cycling. The inclusion of a separate test would have enabled a better understanding of potential anaerobic performance occurring with RT. However, as mentioned previously, the core concept of this research was to investigate how concurrent resistance and strength training impacted on cycling performance. Therefore, sprinting during an actual performance test was seen as being more beneficial to analyse than a separate test.

Another possible reason to explain the lack of improvement in the sprint performance from the group performing resistance training in the present study relates to the concept of lag time. Lag time has been explained by Stone and colleagues (2003) as the time needed by an athlete to utilise the gains made from training. In the current study, it is possible that the six weeks of resistance training followed immediately by post-testing (up to 14 days after the last training session) was not a sufficient amount of recovery time needed for the cyclists to adapt and develop muscular power that could be translated into cycling performance.

A final limitation that may have impacted on the cycling performance tests was that only resistance training was controlled during the current study. The participants were free to control their own endurance training, which was recorded on the training diary provided. The results show that there were no significant changes in training distance but that there was a slight change in the time spent cycling, with the control group increasing their time and the training group decreasing their time. Considering this change in time spent cycling occurred without a change in distance cycled, it can be

inferred that the intensity of the control group may have declined slightly. However, this suggestion may not be correct since the intensity of each individual ride was not assessed and the results could be skewed by longer recovery rides at lower intensities rather than a lower intensity throughout the entire intervention program. Furthermore, some training diaries entries were incomplete in terms of heart rate or RPE and thus analysis of intensity was not always possible.

5.4 Specificity of the exercise program

The principle of specificity does not appear to be met in regards to performing resistance training to enhance cycling performance. The principle suggests that the modality of training should match closely the requirements of the sporting performance. Pearson et el. (2000) explain that training should concentrate not only on the required energy pathways but that speed of movement is important to replicate the rate at which muscles are moving during the activity. It seams feasible to imagine that resistance training, incorporating both heavy strength and high velocity power training, may improve cycling performance and specifically sprinting performance. However for improvements to result, it is important that the major muscles recruited during cycling would be recruited in the training program. The major muscles used during cycling are the vastus medialis, vastus lateralis, and soleus (Hug, Decherchi, Marqueste, & Jammes, 2004). Therefore the resistance training program in the current study specifically recruited the muscles of the lower limb with emphasis on the quadriceps and calves without ignoring the hamstring group. It was important that the training did not result in undue muscular imbalances which could result in injury.

Since the production of power is central to cycling performance (Vogt et al., 2006), the resistance training program used in the current study was developed with this in mind. Each down stroke in cycling is a unilateral action with little assistance from the opposing leg, which is either pulling up or creating a small resistance against the downward power stroke. Therefore the current training included a large number of exercises such as single-leg leg press, single-leg calf raises, and single-leg jump squats that trained the muscles recruited in cycling in a unilateral manner. This type of training was performed to assist the muscles to adapt to the type of activity they would perform on the bike. Furthermore, previous research has suggested that the gains associated with resistance training are not reduced if unilateral type training is performed over bilateral training and that unilateral training may even be beneficial (McCurdy et al., 2005).

Two previous studies also used unilateral resistance training with well-trained cyclists (Bastiaans et al., 2001; Paton & Hopkins, 2005). However, both of these studies performed only explosive type resistance training whereas the current study used an undulating model for resistance training. Both of the previous studies also found that sprinting performance improved with this type of unilateral training. However, as mentioned previously, the study by Paton and Hopkins (2005) included high intensity training and both studies used isolated tests to measure changes in sprinting performance. It is possible that the nature of the resistance training used in this study was not an optimal design to enhance the endurance and sprint performance.

5.5 Strength

It was hypothesised that concurrent endurance and resistance training would improve maximal strength and maximal sustainable power off the bike. Furthermore, it was expected that no physical characteristics would change given the short time frame for the training intervention. Body mass and leg girth remained unchanged in both groups over the course of the study. None of the previous studies with well trained cyclists have measured leg girth, but two have measured the change in body weight with varying results (Bishop et al., 1999; Paton & Hopkins, 2005). Bishop et al. (1999) found that six weeks of heavy strength training resulted in an increase in body mass in trained women cyclists. However, a period of 4 – 5 weeks was insufficient to cause any change in the body mass of well trained male cyclists (Paton & Hopkins, 2005). It is common that body weight remains unchanged in males after a short term concurrent resistance and endurance training program. This finding has been replicated with both trained and untrained men (Izquierdo, Hakkinen, Ibanez, Kraemer, & Gorostiaga, 2005; Paavolainen et al., 1991; Paton & Hopkins, 2005). Both body mass and thigh girth were measured in a previous study on national level cross country skiers who undertook a six week period of concurrent training performing both heavy and explosive resistance training (Paavolainen et al., 1991). It was found in that study that both mass and leg girth did not change after the six weeks of training. This is a similar finding to the current study and suggests that concurrent training using both heavy and light loads performed for a period of six weeks is unlikely to cause any physical changes in trained athletes. It must be acknowledged however, that girth is a measurement only of total leg thickness which cannot differentiate between muscle and fat mass. Furthermore, muscle

architecture may change due to training and these findings cannot be detected by measuring girth.

Increasing muscular strength is commonly found when concurrent training is performed (Hennessy & Watson, 1994). The current study used only a back squat to assess lower limb strength and found that the training program resulted in a 26% increase in muscle strength. Despite program differences and gender differences, the current result is very similar to the increase of 23% in squat strength found after 6 weeks of resistance training by Bishop et al. (1999) on female cyclists. It is interesting to note that the training program employed in the current study reproduced and exceeded strength gains made using only heavy resistance training since this study was the first to examine the influence of a multidimensional resistance training approach on trained cyclists. All previous work in this area has utilised only one form of resistance training (heavy training, explosive training, or training for muscular endurance) throughout the entire intervention program (Bastiaans et al., 2001; Bishop et al., 1999; Jackson et al., 2007).

The most recent study in this area which examined the effects of two different types of resistance protocols within a concurrent training schedule on cyclists also found strength increases of between 22 and 30% for the squat (Jackson et al., 2007). The group which performed heavy training with low repetitions outperformed the high repetition low load group. The similar strength improvements in the present study suggests that an undulating periodised resistance training approach is able to produce gains matching a more tightly structured program over a short duration of six weeks. Furthermore, the limited resistance training period is not conducive to a linear periodised program which is used mainly to avoid overtraining and peaking at the right time (Stone et al., 1999).

5.6 Power

Power off the bike was assessed via a repeat jump test. The test measured the number of jumps, average power of all jumps and the fatigue index over a 30 second period. While there were no significant improvements for either group, an ES calculation (ES = 0.5) suggested that there was a slight to moderate increase in ability of the RT group to become less fatigued during the test. This suggests that the RT group was more likely to produce a constant power through the duration of the test whereas

the control group produced higher forces initially but fell away somewhat towards the end of the test. However these results must be viewed cautiously since there was a significant difference between the groups for the fatigue index variable and the resistance training group had more scope to improve in this area. Considering that the RJ30 test has not previously been used in any previous study, this makes comparison of the results with other methods of power production very difficult.

5.8 Reliability

A secondary aim of this study was to look at the reliability of the cycling tests that were employed both prior to and after a training intervention period. A maximal aerobic capacity test on a cycle ergometer is a very common form of measuring aerobic and anaerobic markers and has been shown to be reliable with a variety of groups of individuals from athletes (Weston & Gabbett, 2001) to adolescents (Pivarnik, Dwyer, & Lauderdale, 1996). VO_2max (CV ~ 2.0; ICC ~ 0.89) and peak power output (CV ~ 2.0; ICC ~ 0.96) during a maximal aerobic capacity test were found, as expected, to be very reliable during this study.

It was an important consideration of the study that the TT that was performed was reliable. Since the TT used in this study was based on a novel design, it was important to test its reliability. The overall time taken to complete the TT was found to be very reliable (CV = 1.3; ICC ~ 0.92), as were the 250m and 1km sprinting components of the TT. These results suggest that the current time trial design can be used with confidence since it was found to have a similar CV to that reported by other authors that examined time trials with (Schabort et al., 1998) and without a sprint component (Jeukendrup, Saris, Brouns, & Kester, 1996; Laursen, Shing, & Jenkins, 2003; Paton & Hopkins, 2005).

6.0 CONCLUSION AND FUTURE DIRECTIONS

In summary, the current study found that concurrent training in well trained cyclists appears to offer no benefits to time trial performance or sprinting performance within a time trial, when compared to cycle training performed in isolation. It is important to realise that the time trial employed in the current study, containing sprinting sections, has not been validated against a typical time trial performed over a similar distance that does not contain any sprinting. It is suggested that this should be

assessed in the future in order to determine whether the cyclists in the current study were under the same physical and physiological strain as cyclists from previous literature. It is also noteworthy that the undulating resistance training protocol resulted in a significant strength enhancement despite the concurrent training that was performed.

Testing methods were found to be reliable both prior to and after a training intervention. This suggests that future studies need not repeat testing protocols so long as a familiarisation trial is offered prior to commencement of the study. Reducing the number of testing sessions is likely to increase subject willingness to participate in demanding training studies.

Lastly, despite the fact that no significant changes in most measured variables occurred in the current study, participants often mentioned that they felt as if their cycling was improving and felt ‘stronger on the road’. There is the possibility that the training may have resulted in delayed benefits consistent with supercompensation, whereby the cyclists might have improved once they had recovered from the potentially fatiguing effect of the concurrent training. Future research that delays the testing of cyclists after a period of concurrent training would be able to provide insight into this concept.

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8.0 APPENDICES

Appendix A

Example of training diary

Week #: ___	Time spent riding	Distance Covered (session)	Average Heart Rate	Session RPE	Other Activities	Cumulative Time (week)	Cumulative Distance (week)
Monday							
Tuesday							
Wednesday							
Thursday							
Friday							
Saturday							
Sunday							

Appendix B

CR-10 rating of perceived exertion scale

Rating	**Descriptor**
0	**Rest**
1	**Very, Very Easy**
2	**Easy**
3	**Moderate**
4	**Somewhat Hard**
5	**Hard**
6	**–**
7	**Very Hard**
8	**–**
9	**–**
10	**Maximal**

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., et al. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research, 15*(1), 109-115.

Appendix C

Exercise Training Session
RPE Recording Sheet

Subject ID: ________

Date: _____________

Session Type: __H__ (3 sets, 8-12 reps)

Session N^{o}: _______

Warm up: Bike 5 minutes

Exercise		**Set 1**	**Set 2**	**Set 3**	**Overall**	**Comments**
Single-Leg Leg Press $^{kg}/_{RPE}$						
Knee Extension						
Knee Flexion						
Standing Calf Raises						
Crunches						
		Session Rating				

Appendix D

Exercise Training Session
RPE Recording Sheet

Subject ID: ________

Date: _____________

Session Type: __S__ (4sets, 5 reps)

Session N^{o}: _______

Warm up: Bike 5 minutes

Exercise		**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Overall**	**Comments**
Lunges $^{kg}/_{RPE}$							
Squats							
Straight-leg Deadlift							
Seated Calf Raises							
Incline Sit-up							
		Session Rating					

Appendix E

Exercise Training Session

RPE Recording Sheet

Subject ID: ________

Date: _____________

Session Type: __P__ (3 sets, 5/6 reps)

Session N^{o}: _______

Warm up: Bike 5 minutes

Exercise		Set 1	Set 2	Set 3	Overall	Comments
Jump Squats $^{kg}/_{RPE}$						
Single-Leg Jump Squat						
Clean Grip Deadlift						
Single-Leg Calf Raise						
Back Extension						
		Session Rating				

Appendix F

Subject recruitment advertisement

Optimal Training for Endurance Cyclists

Concurrent Strength & Endurance Training

Edith Cowan University is currently involved in several research projects targeting cycling performance, training, and recovery. This current study is aimed at determining optimal training strategies for endurance cyclists. Concurrent strength and endurance training has previously resulted in enhanced performance for long distance runners and cross-country skiers and we believe that it can improve your cycling performance too.

This is a great opportunity to participate in research and reap the rewards. The benefits to you are as follows:

- $\dot{V}O_2$max testing to assess your level of aerobic fitness and determine thresholds. This will assist your training and your overall riding performance.
- Individualised weight training programme based on strength and power measurements. The programme is specific to cycling and is expected to improve performance without affecting your riding.
  (not all participants will perform resistance training)
- Time trial assessments to measure your performance and improvements and provide you with additional physiological information over a 30km time-trial course.

To take advantage of this excellent opportunity you must be male aged 18-40 years, be cycling competitively for at least 12 months and have not performed any weight training in the past 6 months.

If you are interested in participating please contact Greg Levin on
[redacted] or email g.levin@ecu.edu.au

Appendix G

Information for Participants

For the study

The Effect of Concurrent Strength and Endurance Training on Physiological and Performance Parameters of Well Trained Endurance Cyclists

Thank you for expressing an interest to participate in this research study.

Purpose of the study

The objective of this study is to determine whether cyclists are able to improve their performance if they perform resistance training while maintaining their endurance training. Performance improvements following resistance training have been shown in runners and cross-country skiers, but we don't know if weight training is helpful to cyclists or not. This study will help us understand whether or not coaches and cyclists should incorporate resistance training in their regular training programs.

Research outline

If you agree to participate in this study you will be required to visit the laboratory on 10 separate occasions. These visits will last approximately 90 minutes and will involve performing various forms of exercise tests. You will also randomly be assigned to either a resistance training group or a non-resistance training group. The resistance training group will be required to commence a six week resistance training program (3 days/week) whereas the non-resistance training group will maintain their normal cycling training habits for six weeks. Measurements will be recorded before and after the six week training period to see if there have been any changes with the different training programs.

All testing and training will be done at Edith Cowan University (Joondalup campus). The first two laboratory visits, occurring over two consecutive days, will allow you to familiarise yourself with the testing equipment and procedures. The next four visits will be used to collect accurate baseline measurements which will be compared to the final sets of measurements taken during the last four visits to the laboratory, which occur after the six week training period. It is important to note that all testing occurs over a two day block.

What exercises will you be required to perform?

All subjects will be asked to perform the following exercises:

1. *Maximal Strength Test* – This will require you to perform a series of squat exercises with a loaded bar to determine the maximum amount of weight that you can successfully lift once. These tests are used as a means of quantifying leg strength and will be used to determine training weight if you are assigned into the training group.
2. *Power Tests* – These tests will require you to perform unloaded (no extra weight added) jumps on a force plate to determine your power capacity. This information will be used to measure the success of the training program.

3. $\dot{V}O_2max$ *test* – This test will require you to cycle on a stationary bike at an easy workload (100 Watts) for 5 minutes, after which the intensity will get progressively harder (increase by 50 Watts) every five minutes until you can no longer pedal at a cadence of 60 rpm. Throughout the duration of this test you will wear a mouthpiece attached to a gas analyser to measure how much oxygen you consume. The results of this test will provide you with a good indication of your fitness level.
4. *30-km time trial* – You will be required to perform a maximal effort 30-km time trial with intermittent 250-m and 1-km sprint sections. This test will assess and monitor your level of cycling performance.

Measurements recorded during testing

Several physiological and performance measurements will be collected throughout the testing procedures. These include:

1. *Heart Rate* – For all tests performed on the bike ($\dot{V}O_2$ test and time trial) you will be asked to wear a heart rate monitor which will allow accurate recording of your heart rate during testing.
2. *Rating of Perceived Exertion* (RPE) – RPE is a subjective measure to determine how you feel at any given time, and is usually taken whilst performing or shortly after completing exercise. RPE will be monitored during cycling tests, resistance training sessions, and also recorded 30 minutes after each resistance training workout.

Benefits to participating

By being involved in this study you will undergo extensive strength, power, and aerobic testing which will provide you with a very accurate representation of your aerobic fitness and muscle strength levels. The information collected may assist you with your future training by allowing you to target specific areas of strengths and weaknesses in order to improve your cycling performance.

Ethical considerations and risks

As this research involves performing exercise it is important that you believe that you possess the necessary physical conditioning required and are free from any illness and injury when choosing to participate in this study.

During the training period you may also experience muscle soreness associated with resistance training. This is a natural process occurring as muscles adapt to the training. The soreness does not usually last beyond 48 hours and is most likely to occur after an initial bout of resistance exercise. As the muscles adapt quickly you will not likely experience soreness after every session.

There is also a risk of injury when beginning resistance exercise; however injury generally results from incorrect technique. As you will always be supervised and guided during training and your technique monitored, injuries of this nature should be avoided.

This research project has been approved by the Edith Cowan University Human Research Ethics Committee.

Confidentiality of information

The information collected in this study will be used to prepare a scientific report to be published in an academic journal. The information will only be available to Greg Levin and his team of researchers. All data collected throughout this study will remain strictly confidential. When the information is analysed you will in no way be identifiable. The data collected from this study will be analysed on a group basis and in no way are you in competition with any other individuals in the study. The information collected in this study will be stored under file in the School of Exercise Biomedical, and Health Sciences for a period of 5 years. After this time the information collected during the course of the study will be destroyed. At the conclusion of the study you will be provided with your own results and a copy of the final report should either be requested.

Voluntary Participation

Your participation in this study is entirely voluntary. No explanation or justification is needed if you choose not to participate. Further, if you decide to participate it is important that you are aware that you are free to withdraw from the study at anytime without prejudice. If you choose to withdraw, you have the right to request that any personal information collected up to that point in the study is returned to you without question.

Requirements

As this study is a training study aimed at assessing differences over time it is requested that you adhere to the requirements of your group. The non-training group will be required to maintain their regular training regime whilst the training group will be required to comply with their 3 days/week training program. It is also important that no new exercise or activities be commenced during the duration of the study as this may influence the results. A secondary requirement is that you will be able to travel to Joondalup to perform all training and testing. Unfortunately, since this is an unfunded study, participants will not be able to be reimbursed for travelling costs.

Should you have any questions relating to any of the information provided above, please feel free to contact myself, Dr Paul Laursen (08 6304 5012) or Dr Mike McGuigan (08 6304 2118) for further explanation. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact the Research Ethics Office on telephone (08) 6304 2170.

Yours sincerely,

Greg Levin
School of Biomedical and Sports Science, Edith Cowan University

Appendix H

Informed Consent Form

The Effect of Concurrent Strength and Endurance Training on Physiological and Performance Parameters of Well Trained Endurance Cyclists

This form serves to clarify that I agree to participate in the above mentioned study as a volunteer. I believe that I possess the necessary physical conditioning required to complete this training study and am currently not suffering from any illness or injury that may limit my participation. Furthermore as a volunteer I understand that I am free to withdraw from the study at any time without prejudice or penalty.

I agree to participate in the following activities:

- Maximal graded exercise test ☐
- 30-km time trial ☐
- Maximal strength and power testing ☐
- A six week training program ☐

I understand that data collected during this study will remain confidential and that my identity will be protected. However, I consent to the researchers using the information provided for publication so long as my identity remains confidential.

I have been informed that any question arising throughout the duration of this study can be referred to the research team consisting of Greg Levin (0403 138 765), Dr Paul Laursen (08 6304 5012), and Dr Mike McGuigan (08 6304 2118).

I [print name] ________________________________ have read and understood the above information as well as the information letter to participants and have had any question raised answered to my satisfaction. I agree to participate in the above research freely and without coercion.

Signed ________________________________ Date: ____ / ____ / ________

Greg Levin
School of Exercise, Biomedical and Health Science
Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
E-mail: g.levin@ecu.edu.au
Phone: [redacted]

Appendix I

Strength and Power Tests

Subject: ___________________________
Date: _______________________________

1- RM Squat

Set	Weight
Warm up (6 Lifts)	
Warm up (3 lifts)	
1 – RM attempt	
1 – RM attempt	
1 – RM attempt	
1 – RM attempt	

Countermovement Jumps

Jump	Force	Power	Height
1			
2			
3			

Squat Jump

Jump	Force	Power	Height
1			
2			
3			

Repeated Jump

Jump	
1	

Appendix J

Time Trial Recording Sheet

Subject ID: ______________________

Date: ___________________________

TT: 1 ☐ 2 ☐ 3 ☐ pre

TT: 1 ☐ 2 ☐ post

Clock Times:

Start: ______:_________:________

4km: ______:_________:________

9km: ______:_________:________

14km: ______:_________:________

19km: ______:_________:________

24km: ______:_________:________

29km: ______:_________:________

RPE:

After 4km Sprint:	_______	(4.5km)
After 9km Sprint:	_______	(10.5km)
After 14km Sprint:	_______	(14.5km)
After 19km Sprint:	_______	(20.5km)
After 24km Sprint:	_______	(24.5km)
After 29km Sprint:	_______	(end of test)