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EDITH COWAN UNIVERSITY

School of Exercise, Biomedical and Health Sciences

Does training with PowerCranks™ affect economy of motion, cycling efficiency, oxygen uptake and muscle activation patterns in trained cyclists?

Masters Thesis

Jack Burns

(BSc. Sports Science)

This thesis is presented in fulfilment of the requirements for the degree of

Master of Science (Sports Science)

Supervisor: Dr Paul Laursen

Associate Supervisor: Dr Greig Watson

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Edith Cowan University

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ACKNOWLEDGEMENTS

I would like to dedicate this thesis to the memory of David Deverell, my Pop, who still remains a strong driving force in my life and someone I miss very much.

Firstly, I would like to thank my supervisors, Paul Laursen and Greig Watson, who have provided much support and advice throughout the development and writing of this thesis. Their friendship has been something that I am very grateful for.

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To my Family, Dad, Mum and Ray, Gran, Luke and Fern. Their support of me in my educational pursuits has been generous and selfless. I simply can not thank you enough.

To Meredith, thankyou for your support and friendship.

Abstract

PowerCranks™ are claimed to increase economy of motion and cycling efficiency by reducing the muscular recruitment patterns that contribute to the resistive forces occurring during the recovery phase of the pedal stroke. However, scientific research examining the efficacy of training with PowerCranks™ is lacking. Therefore, the purpose of this study was to determine if five weeks of training with PowerCranks™ improves economy of motion (EOM), gross efficiency (GE), oxygen uptake (**Error! Bookmark not defined.**$\dot{V}O_2$) and muscle activation patterns in trained cyclists. Sixteen trained cyclists were matched and paired into either a PowerCranks™ (PC) or Normal Cranks (NC) training group. Prior to training, all subjects completed a graded exercise test (GXT) using normal bicycle cranks. Additionally, on a separate day the PC group performed a modified GXT using PowerCranks™ and cycled only until the end of the 200W stage (PCT). During the GXT and PCT, FeO_2, $FeCO_2$ and $\dot{V}_E$ were measured to determine EOM, GE and $\dot{V}O_2$max. Integrated electromyography (iEMG) was also used to examine selected muscular activation patterns. Subjects then repeated the tests following the completion of training on their assigned cranks. No significant improvements were observed for EOM, GE, $\dot{V}O_2$max or iEMG in either the PC or NC group when subjects were cycling with normal cranks during the GXT. Likewise, no significant training effects were observed when PC subjects cycled with PowerCranks™ during the PCT. PC group subjects were significantly less efficient and economical, before and after training when cycling with PowerCranks™ compared to cycling with normal cranks. The results from this study do not support benefits claimed by PowerCranks™, however further research is needed to examine the influence of training with PowerCranks™ on various physiological variables over a more prolonged training duration.

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CHAPTER 1: INTRODUCTION

1.1 Background

Since the introduction of the safety bicycle over one hundred years ago, the modern bicycle has developed into a strong, lightweight, aerodynamic machine that has allowed cyclists to travel at over 50km·h^{-1} for prolonged durations (Lafortune & McLean, 1989a; Padilla, Mujika, Angulo, & Goirena, 2000). In addition to these successful technological advances, research in the fields of exercise physiology, nutrition and biomechanics have helped to advance our understanding of ways in which cyclists can improve their performance (Minetti, Pinkerton, & Zamparo, 2001).

One factor that might influence cycling performance is the distribution of the force that a cyclist's foot applies to the pedals throughout the entire pedal stroke (Kyle, 1996, p. 2). Traditionally, cyclists push down from top dead centre to bottom dead centre and then relax for the recovery portion of the stroke (Lafortune & McLean, 1989b). Lafortune and Mclean (1989a) have suggested how this pedalling technique may be difficult to improve due to certain anatomical, physiological and biomechanical restrictions in the human body, coupled with ingrained motor patterns present from childhood (Schmidt & Wrisberg, 2000, p. 124). Indeed, resistive forces are created when cyclists do not pull up sufficiently, which causes downward pressure to be applied during the recovery stroke (Hoes, Binkhorst, Smeekes-Kuyl, & Vissers, 1968). It has been suggested that this inherent lack of force applied throughout the entire 360° of the pedal stroke may be a major contributor to a lack of efficiency during cycling (Lafortune & McLean, 1989b). Pedal clips and then cleats (clipless pedals) were invented to remedy this problem by attaching the cyclists' feet to the pedals, thereby enabling the cyclist to pull up during the recovery portion of the pedal stroke (Capmal & Vandewalle, 1997). However even with clipless pedals, the distribution of force displayed by the most elite of cyclists was still relatively inefficient as they did not appear to significantly increase the upward force (Faria, 1992).

To further identify and implement better cycling techniques, a significant amount of research has continued to investigate the interaction between the rider and the pedal stroke (Lafortune & McLean, 1989b). Little research is available, however, investigating pedal crank interventions that enforce 360° of force throughout the pedal stroke. It is possible that by altering the biomechanics of the pedal stroke in this way, that both the cycling efficiency and economy could be improved through adaptations to the neuromuscular and cardiovascular systems (Luttrell & Potteiger, 2003). Zamparo, Minetti and Prampero (2002) investigated a pedal crank arm that changed length at different crank angles. The design meant that the pedal crank was longest at 90°, when the leg was pushing down, and shortest at 270° when the leg was pulling up. This intervention elicited significantly lower values for oxygen uptake and corresponding increases in efficiency at higher power outputs with the modified crank prototype compared with a regular crank. The authors attributed this finding to the more effective transfer of energy between the subject and bicycle taking place during the cycling motion (Zamparo et al., 2002). Another study by Ratel, Duche, Hautier, Williams and Bedu (2004) examined the effects of cycling with a noncircular chain ring in thirteen male cyclists. The authors noted that although the design of the chainring was based on optimisation analysis, it did not translate into physiological benefits.

Another idea has been to use a pedal design that has the potential to improve the distribution of force applied throughout the entire 360° of the pedal stroke. PowerCranks™ (PowerCranks, CA, USA) use a patented clutch design that produce simultaneous one-legged cycling, with both legs, to drive the bicycle. This creates a situation by which the cyclist must pull up with each leg on every pedal stroke or the crank will simply remain at bottom dead centre of the pedal stroke and force will not be applied to the pedals. In theory, PowerCranks™ encourage a smoother pedal stroke by altering normal muscle recruitment patterns, therefore stimulating the adaptive processes in those muscles not commonly involved in cycling (Luttrell & Potteiger, 2003). The recruitment of new muscle fibres could in turn could produce an increase in cycling economy and efficiency by lowering the energy expenditure (i.e., through less wasted energy) and producing increases in oxygen utilization. Ultimately, an improvement in cycling performance may be possible with such an

intervention. In a study by Luttrell and Potteiger (2003), it was found that training with PowerCranks™ resulted in lower heart rates and a higher gross efficiency during a 1-h submaximal bout of cycling. However, no group differences were found for maximum oxygen consumption ($\dot{V}O_2max$) and markers of the anaerobic threshold. As there are limited published studies examining the influence of training with PowerCranks™, further studies are required.

1.2 Significance of the study

Cycling is a competitive sport and researchers are continually striving to find new ways to enhance cycling performance. While research examining the influence of pedal clips and cleats has shown limited promise in providing full application of force throughout 360° of the pedal stroke, one promising area that has received little attention is the modification of the crank itself. It is possible that a modified crank arm system (PowerCranks™) will enable cyclists to adapt a more efficient and economical pedal stroke via improvements in various physiological and biomechanical processes, and ultimately lead to improvements in cycling performance. Thus, further research in this area is necessary to determine the influence that PowerCranks™ may have on cycling performance and related physiological and biomechanical measures.

1.3 Purpose of the study

The primary purpose of this study was to determine if outdoor (field) training with PowerCranks™ would result in changes in gross efficiency and economy of motion. A secondary purpose was to examine whether or not training with the modified crank design

resulted in changes in oxygen uptake, ventilatory thresholds as well as changes in muscle activation patterns during cycling.

1.4 Research Questions

I. Does training with a modified crank design (PowerCranks™) alter economy of motion and cycling efficiency when subjects return to cycling with regular cranks?

II. Does oxygen uptake and power output at the respective ventilatory thresholds change while cycling on regular cranks after training with PowerCranks™?

III. Does training with PowerCranks™ alter muscle activation patterns once the subject returns to cycling on regular cranks?

1.5 Hypotheses

I. Training on PowerCranks™ will improve economy of motion and efficiency when cyclists return to using regular cranks.

II. Training on PowerCranks™ will improve oxygen uptake and power output at the ventilatory thresholds when cyclists return to using their regular cranks.

III. Upon returning to regular cranks, certain muscles will increase their activation rates, such as biceps femoris and gastrocnemius, whilst other muscles more commonly used during cycling, such as vastus lateralis, will have slightly reduced activation rates due to the new motor patterns evoked through training with PowerCranks™.

1.6 Definitions of Selected Terms

Variable	Abbreviation	Definition
Bottom Dead Centre	BDC	The point at which the crank arm is positioned so as to point directly downwards.
Crank/Crank arm		The arm that joins the pedal to the bottom bracket axle.
Economy of Motion or Cycling Economy	EOM	The mean oxygen cost per unit of power output applied to the cycle ergometer (Faria, Parker, & Faria, 2005).
(Mechanical) Gross Efficiency	GE	The ratio of work rate to the rate of energy expenditure (Sidossis, Horowitz, & Coyle, 1992).
PowerCranks™	PC	A modified crank design, which integrates a one-way clutch on each crank arm (see http://www.powercranks.com).
Peak Power Output	PPO	Recorded as the highest power output completed during a graded exercise test plus the fraction of the uncompleted stage (Hawley & Noakes, 1992).
Top Dead Centre	TDC	The point at which the crank arm is positioned so as to point directly upwards.
Volume of Oxygen Uptake	$\dot{V}O_2$	The volume of oxygen consumed by a subject (in $L \cdot min^{-1}$ or $ml^{-1} \cdot kg^{-1} \cdot min$).
Maximal Oxygen Uptake	$\dot{V}O_{2max}$	The maximum amount of oxygen a subject consumes before volitional exhaustion occurs (in $L \cdot min^{-1}$ or $ml^{-1} \cdot kg^{-1} \cdot min$).
Ventilatory Threshold 1	$\dot{V}T_1$	The point at which there is an increase in $\dot{V}E/\dot{V}O_2$ with no concurrent increase in $\dot{V}E/\dot{V}CO_2$ (Lucia, Hoyos, Perez, & Chicharro, 2000).
Ventilatory Threshold 2	$\dot{V}T_2$	A marked increase in both $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$ (Lucia, Hoyos, Perez, & Chicharro, 2000).
Resistive Forces		The forces evident when cycling with normal cranks due to the opposite leg (performing the down stroke) being able to lift the other leg (performing the recovery or up stroke) at a faster rate than the recovery leg can perform.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review will examine the available literature that has investigated the foot/pedal interface. Beginning with a brief history of the bicycle and how it has advanced since its introduction, the review discusses the foot/pedal interface, with particular attention given to the forces applied to the pedals during cycling, and how this has advanced pedalling technique. Next, the physiological adaptations needed for successful cycling performance are discussed. Lastly, the review examines an area not extensively researched with regards to the foot/pedal interface; the pedal crank, and how training with a modified pedal crank might function to improve cycling performance.

2.2 Background

The bicycle has come a long way in its short history. Originating from the crude and dangerous designs of the velocipede and later the ordinary (or as it is more commonly known, the penny farthing), came a safer and more effective option, aptly named the safety bicycle (see Figure 1) (Sidewells, 2003, p. 11). Introduced by John Starley in the 1880's and consisting of a rear driven, chain transmission, this design essentially became the basis for which all future bicycles would be based on (Wilson, 1988, p. 220).

Figure 1. The first version of the safety bicycle (In Wilson, 1988, p. 221).

Sidwells (2003, p. 11) notes how the bicycle has been used in many aspects of life over the years, including transportation of items and the sending of messages in times of war, as well as an alternative form of transport. The main reason for the development of the bicycle into what it is today has come about largely because of the desire to go faster in a competitive surrounding (Wilson, 1988, p. 233). With its origins in Europe, bicycling as a recreational and competitive pastime quickly spread around the world, leading to well known events like the Tour de France (Sidewells, 2003, p. 11). The desire to race also produced a desire to find ways of finishing quicker. Over the early part of the 20th century, small but significant advancements were made in the field, including the tubular tyre invented by John Boyd Dunlop in 1888 (Wilson, 1988, p. 220) and the quick-release wheel invented by Tullio Campagnolo in 1927 (Sidewells, 2003, p. 11).

The integration of science into cycling has resulted in a rapid advancement of knowledge and accompanying performance improvements (Minetti et al., 2001). The drive for a scientific understanding of cycling has lead to an explosion of information in areas such as technique, gearing, training and nutrition, all allowing cyclists to achieve progressively faster times (E Faria, D Parker, & I Faria, 2005; Jeukendrup & Martin, 2001). Lafourtune and McLean (1989a) noted that the advancements to the bicycle itself have lead to a refined and specialised machine that is stronger, lighter and more aerodynamic than its predecessors.

2.3 Foot/Pedal Interface

One area of concentrated research, certainly in the field of biomechanics, has been the foot/pedal interface; the point at which the rider transfers energy to the bicycle (Broker & Gregor, 1996, p. 146). Efficient transfer of energy depends on the manner in which the power, including direction and application of force, is applied to the pedals (Kyle, 1996, p. 2). In addition, it has been suggested that the degree of success in cycling is ultimately determined by the ability of the coordinated movements of extension and flexion at the knee to transfer their energy to the bicycle (Pruitt, 1988, p. 20). Hence, if the flexors and extensors can work in unison, cycling performance will be improved. However, it is evident that this coordination between the flexors and extensors is not as effective as it could be (Faria, 1995).

2.3.1 Early Advancements

Initially it was coaches and cyclists, not scientists, who developed techniques to improve pedalling efficiency, based on their own reasoning and observations. One such approach came about when coaches realised how cyclists appeared to push and pull on the pedals rather than producing a fluent cycling motion. Consequently, cyclists were taught to "cycle (pedal) in circles" (Sidewells, 2003, p. 100) in order to increase pedalling efficiency. The use of verbal feedback played a vital role in teaching cyclists how they could improve on aspects of this technique (Schmidt & Wrisberg, 2000, p. 282). However, it did not provide the detailed analysis that may aid in significantly improving cycling performance (Sanderson & Cavanagh, 1990). Recently, biomechanists have examined the science behind 'cycling in circles' and found that the technique teaches cyclists to pull up during the recovery stroke, hence reducing the resistive forces evident in this phase (Lafortune & McLean, 1989a).

2.3.2 Verbal and Visual Feedback as a Mechanism of Improvement

With the introduction of technical scientific interventions aimed at changing the way in which cyclists applied forces to the pedals, came large advancements in the area of the

foot/pedal interface. The use of amplified onscreen feedback of the forces that cyclists' apply to the pedals (augmented visual feedback) has proven to be an effective way of improving pedalling technique in experienced recreational cyclists (Sanderson & Cavanagh, 1990). New complex computer analysis and representations of real-time feedback to the cyclist has taken improvements to another level (Lafortune & McLean, 1989b). However, computer-based feedback does not directly condition the muscles, as only the way upon which a cyclist interprets and acts on that feedback will determine its effectiveness. In addition, the prior engrained motor pattern often returns if the cyclist does not concentrate on the newly learned technique (Schmidt & Wrisberg, 2000, p. 124).

2.3.3 Muscle Mapping in Cycling

In light of the outlined shortcomings of visual and computer-based feedback, researchers have taken further steps in an attempt to improve pedal stroke efficiency. The mapping of muscular involvement during the pedal stroke (Figure 2) has provided useful information about muscle patterns that might benefit from training in order to enhance pedalling efficiency (Pruitt, 1988, p. 22). For example, Pruitt (1998, p. 22) has shown how the more powerful hip and knee flexors and extensors combine to provide a coordinated movement in which the hamstrings and quadriceps work in unison to produce the pedalling motion. However, as mentioned, coordination between the flexors and extensors is not as effective as it could be (Faria, 1995), likely due to the resistive, inefficient forces in the pedal stroke. Perhaps if certain muscles could be more activated at certain phases of the pedal stroke, namely during the recovery phase, then pedalling efficiency might be improved.

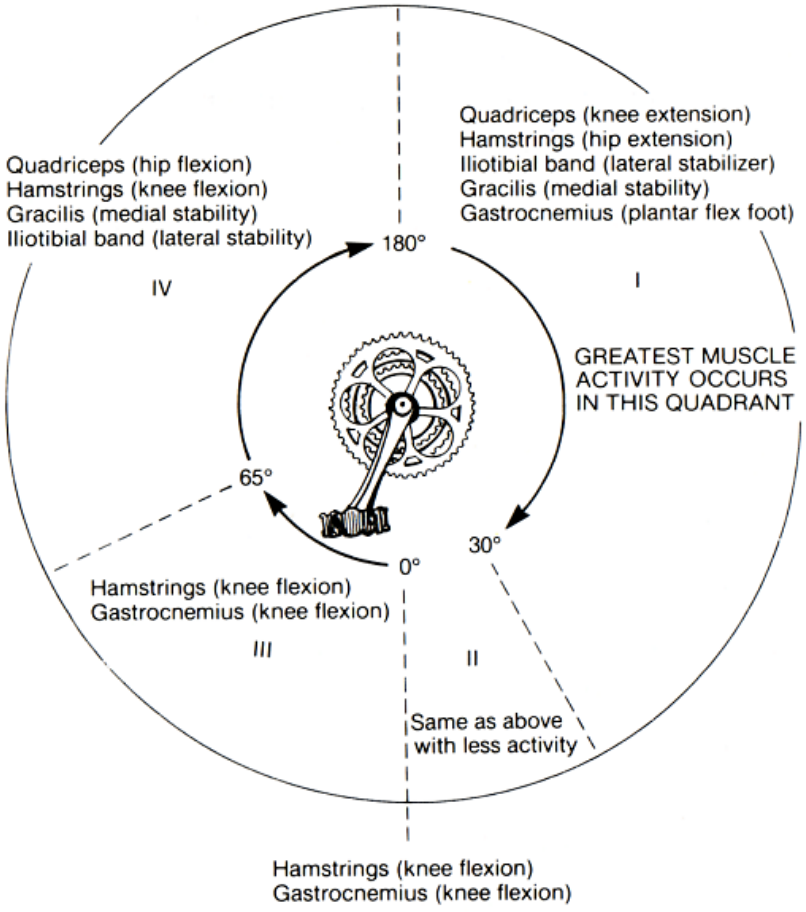

Figure 2. Diagrammatic interpretation of EMG studies examining the pedal stroke with toe clips in a seated position (from Pruitt, 1988, p. 23).

2.3.4 Pedalling Symmetry

Another potential contributor to pedalling inefficiency arises from the discrepancy in output that has been observed between the left and right limbs. For example, leg asymmetry can lead to differences in power output between the legs, causing reduced performance, increased knee loads, and eventually overuse injuries (Smak, Neptune, & Hull, 1999). Sargeant and Davies (1977) have shown that the mean peak force during the phases of leg flexion and extension (adjusted for the doubled output of two-legged exercise) was similar between one- and two-legged cycling. This indicates that single-leg pedalling may not condition the leg any more so than two-legged cycling. In contrast, Ting, Kautz, Brown and Zajac (2000) suggest that unilateral pedalling increases force output during the flexion phase due to its effect on the interlimb neural pathways through which both limbs communicate

during a normal pedal stroke. Thus, cyclists may pull up more on the recovery portion of the pedal stroke when performing one-legged cycling.

2.3.5 Remediation of Problems in Bicycling Pedalling

The first attempt to rectify pedalling inefficiencies and improve technique and performance involved attaching the cyclist's shoes to the pedals with nails or screws (Broker & Gregor, 1996, p. 147). The introduction of pedal clips and later cleats, now standard accessories on most bicycles, provided a safer way to attach the shoes to the pedals (Faria, 1992). Despite their acceptance by cycling enthusiasts, it has yet to be proven that pedal clips or cleats improve cycling performance (Capmal & Vandewalle, 1997), as cyclists still display some elements of resistive forces during the recovery phase of the pedal stroke when clips or cleats are used (Broker & Gregor, 1996, p. 150). The following section examines the rational and evidence for using clips and cleats for improved cycling performance.

2.3.6 Toe Clips and Cleats (The case for and against)

Ideally pedal (toe)-clips or cleats hold the ball of the foot over the centre of the pedal allowing the cyclist to push down more effectively and also to pull up in the recovery stroke (Visich, 1988, p. 122). Some authors have suggested that the use of toe-clips or cleats improves cycling form by allowing the cyclist to actually pull up during the recovery stroke (Faria, 1992). This has not been shown scientifically however, because studies have not found any advantage of pedal-clips or cleats over regular unattached pedals (Capmal & Vandewalle, 1997; Evangelisti, Moser, Kuesel, Verde, & Miles, 1999)

Some studies have suggested that pedalling with clips may increase $\dot{V}O_{2max}$ and mechanical efficiency (Visich, 1988, p. 122), however most of the evidence in support of using toe clips is largely anecdotal and there is no significant research suggesting such a benefit (Broker & Gregor, 1996, p. 147). In fact, Broker and Gregor (1996, p. 152) have suggested that the effective force patterns measured in experienced cyclists using floating pedals, toe clips and cleats were similar. In opposition to this view however, more highly trained cyclists may apply less downward force (inefficient pressure) during the recovery

phase (see Figure 3). Nevertheless, Campmal and Vandewalle (1997) suggested that, as a result of regular crank training, the hamstrings become unable to lift the leg at a quicker rate than that of the quadriceps of the opposite leg. Hence, neither pedal clips nor cleats would appear to make a significant difference to the recovery of the pedal stroke. Ultimately the pedal rises at a rate that is faster than the leg can lift because of the force being applied through the other pedal. Therefore the pedal assists with the upwards lift of the leg during the recovery phase (Broker & Gregor, 1996, p. 150) and a resistive or negative force results.

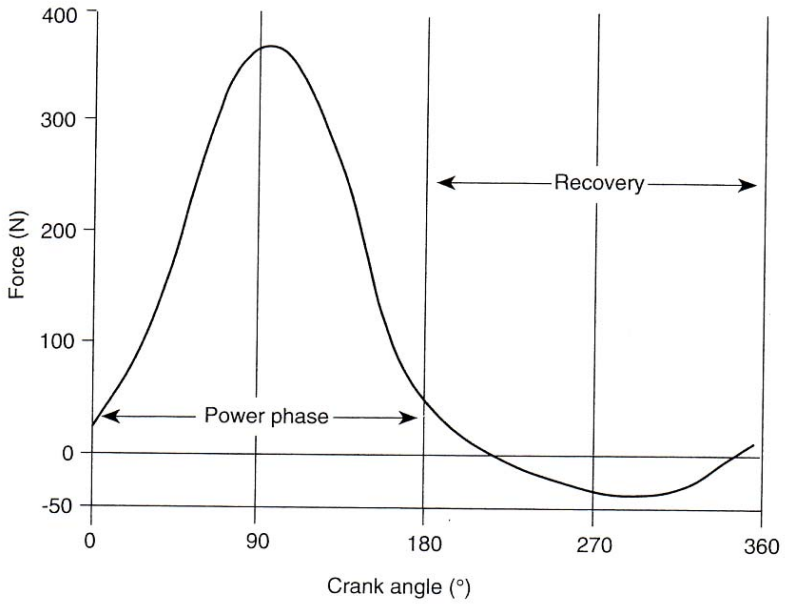

Figure 3. Force effectiveness patterns versus crank angle for a U.S. national team cyclist pedalling at 350 W and 90 revs·min^{-1} (from Broker and Gregor, 1996, p. 151).
Note. 0° on the horizontal axis represents top dead centre and 180° represents bottom dead centre.

Other cycling scientists also maintain that pedal clips or cleats provide little or no benefit to the cyclist. For example, biomechanists Smak, Neptune and Hull (1999) suggested that cyclists who focus too much on aspects of the pedal stroke may inadvertently reduce the power of the down stroke, and that by changing their biomechanics, cyclists may possibly increase their chance of developing an injury (eg. knee pain and other overuse problems).

Coyle et al. (1991) have also shown that elite cyclists produce higher power outputs during the downstroke, in turn making it more difficult for the hamstrings to effectively carry out the recovery stroke. Hence, there is little evidence to suggest that significant performance benefits will be gained from using toe cleats or clipless pedals with regards to reducing force during the recovery portion of the pedal stroke.

Because using toe clips or cleats does not appear to improve cycling efficiency, further research is required to find alternative ways to increase efficiency at the foot/pedal interface.

2.4 Physiological Adaptations to Endurance Exercise Training

It is important to review the associated physiological processes involved with cycle training in order to examine ways in which cycling performance may be improved. Cycling performance may be improved through the adoption of superior motor recruitment patterns that enable efficient cycling technique, improvements in economy of motion and enhancements in oxygen uptake.

Kyle (1996, p. 3) notes how the types of muscle fibres a person naturally possesses (i.e., percentage of fast and slow twitch fibres), and the genetic capacity of one's cardiovascular system to supply oxygenated blood to the working muscles, are key determinants of potential to perform successfully in endurance events. However, adaptations still occur to both the cardiovascular and neuromuscular systems as a result of endurance exercise training (Jones & Carter, 2000). It is also apparent that factors such as cadence, posture, and technique can influence cardiovascular, neuromuscular and biomechanical aspects of cycling, which in turn should enhance both cycling efficiency and economy (Li, 2004; Sarre, Lepers, Maffiuletti, Millet, & Martin, 2003). Improvements in economy of motion and efficiency correlate highly with increases in cardiovascular factors (O'Toole & Douglas, 1995) and neuromuscular adaptations, such as more efficient neural input to the available muscles (Lepers, Hausswirth, Maffiuletti, Brisswalter, & Van Hoecke, 2000).

Indeed, a more efficient muscle movement and coordination should lead to a decrease in oxygen uptake for a given amount of work (Luttrell & Potteiger, 2003). Thus, it is pertinent to examine whether or not the muscular and cardiovascular adaptations that may occur as a result of training to improve cycling technique could benefit the cyclist.

2.4.1 Electromyography and Muscular Adaptations

Differences in performance amongst cyclists with the same level of $\dot{V}O_{2max}$ may be due to adaptations within the trained skeletal musculature that do not necessarily involve an increase in oxygen extraction (Coyle, Coggan, Hopper, & Walters, 1988). Surface electromyography (EMG) allows the measurement of the total electrical activity of a muscle (Duc, Betik, & Grappe, 2005). As a result of training, muscle activation parameters are changed via central neural structures in response to the novel movements (Mileva & Turner, 2003). Furthermore, the nervous system is readily able to adapt to these new mechanical actions very promptly (Dietz, 1997). As more powerful and coordinated muscle movements produce better cycling performance, it is important to consider how muscle recruitment patterns adapt to cycling, and how training and training devices may aid with these adaptations.

The motor recruitment patterns of leg muscles have been studied during cycling using EMG (i.e., Figure 4). For example, Ryan and Gregor (1992) assessed the activation patterns of eight lower leg muscles at different phases of the crank cycle. The authors concluded that muscles crossing two joints (e.g. rectus femoris and gastrocnemius) were associated more highly with power distribution, thereby allowing the power generated to be spread across all the joints of the lower limb resulting in a greater ability to propel the bicycle forward. Whilst those muscles that only crossed one joint (e.g. vastus lateralis) were more highly associated with power generation (Ryan & Gregor, 1992).

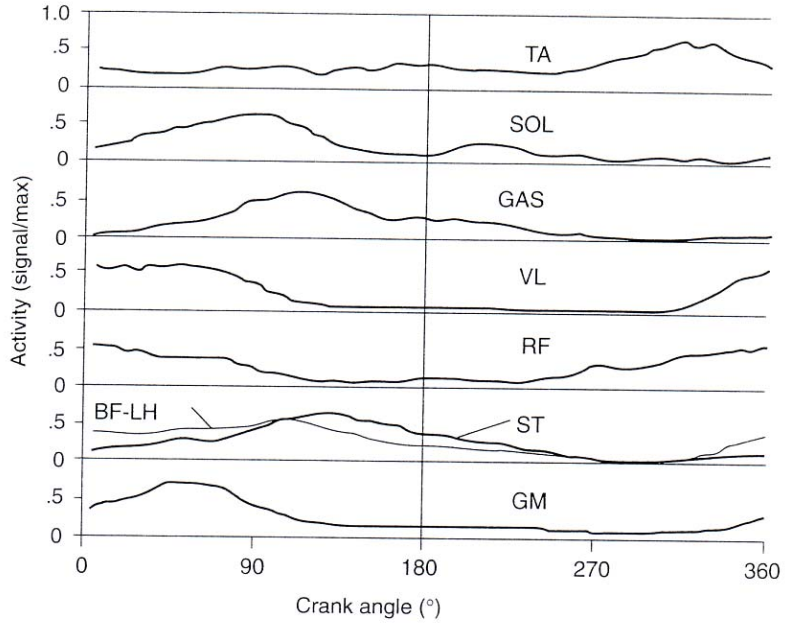

Figure 4. Muscle activation patterns for eight muscles of the leg monitored during steady state cycling. Muscles indicated are tibialis anterior (TA), soleus (SOL), gastrocnemius (GAS), vastus lateralis (VL), rectus femoris (RF), semitendinous (ST), biceps femoris – long head (BF –LH), and gluteus maximus (GM) (data from Ryan & Gregor, 1992).

Broker and Gregor (1996) measured joint powers (the amount of power generated at a particular joint) and showed that the hamstrings and quadriceps contribute to the majority of the power produced during cycling. Indeed, the knee joint in this study was shown to produce the highest peak power, a value more than twice that found at the hip or ankle joint (Broker & Gregor, 1996, p. 158). This finding confirms the powerful forces produced by the hamstrings and quadriceps during the pedal stroke. However, the quadriceps muscle activity tends to continue further into the crank cycle than ideal because its contraction/relaxation speed is not fast enough to keep up with typical pedalling cadences (Faria, 1995). Capmal and Vandewalle (1997) also suggest that the use of regular cranks does not allow the hamstrings to lift the leg at a quicker rate than that of the opposing quadriceps. Hence, neither pedal clips nor cleats would make a significant difference to the recovery stroke in the cycling action. Ultimately, the pedal rises at a rate that is faster than the leg can, so the pedal assists the leg

up (Broker & Gregor, 1996, p. 150). This would seem to be reflected by the fact that at faster pedal rates, the cycling action appears to be less efficient (Faria, 1995). Hence, interlimb biomechanics seem to be a limiting factor in the pedal cycle. Reducing the reliance of one leg on the other may produce improved economy and efficiency during cycling. This premise is supported by Ting, Raasch, Brown, Kautz and Zajac (1998) who suggest that cycling tasks, when performed unilaterally, do not use the same muscular coordination when compared with a bilateral action.

Even though muscular involvement over the pedal stroke is similar between novice and elite cyclists, elite cyclists are more efficient than novice cyclists (Faria, 1992). Pruitt (1988, p. 22) suggested that the greater efficiency seen with elite cyclists occurs because their stimuli for muscle contraction are greater in duration and intensity. Thus, the level of activation of the muscles possibly explains differences in efficiency between novice and elite cyclists. This increased duration of activation may allow elite cyclists to apply more effective pressure to the pedals (Lepers et al., 2000) rather than just a quick push-pull type motion. Future research should establish whether elite cyclists actually learn to pedal more efficiently through their years of training, or whether they are just naturally very efficient. If efficiency can be learned, the question arises as to whether efficient cyclists might stimulate the main hip and knee flexors more, or whether they recruit other muscles of the lower leg better, or both?

There is an increased energy cost and reduced mechanical efficiency and economy at the higher cadences, preferred by trained cyclists(Takaishi et al., 1998). If a cyclist cycled with a crank design that demanded more independent power production from each leg, it would be expected that their cadence would be reduced because of the increased demand on each individual leg. Thus, it would be expected that their mechanical efficiency, and perhaps performance, would increase as a result of neuromuscular adaptations to the crank. It is possible that the frequent use of such a crank could result in neuromuscular adaptations within approximately four weeks, assuming that neuromuscular adaptations to overload training are evident following only 4 weeks of training (Sale, 1988), even in cyclists (Creer, Ricard, Conlee, Hoyt, & Parcell, 2004).

A potential limitation of the use of such a modified crank is the increased muscle usage while pedalling, resulting in a greater demand from the muscles. However, this limitation may be corrected over time because it is noted that as muscles become better trained, there is reduction in the overall whole body oxygen demand, and hence an increase in efficiency (Luttrell & Potteiger, 2003). Coyle, Coggan, Hopper and Walters (1988) have suggested that because elite cyclists tend to pull up during the pedal stroke more than novice cyclists, the knee extensors of the opposite leg perform less work. Thus, there may be less of a reduction in muscle glycogen usage in the extensors due to a greater sharing of work by the muscle fibres during leg flexion and extension (Coyle et al., 1988). Coyle et al. (1988) also suggests that it is possible to dramatically reduce muscular stress by being better able to distribute muscular work of the lower leg muscles. Another possible explanation for the increased efficiency of the musculature may be that cyclists with a greater percentage of Type I fibres are more efficient (Jones & Carter, 2000). Takaishi et al. (1998) suggest that a greater recruitment of slow twitch muscle fibres with lower recruitment thresholds than fast twitch muscle fibres may increase mechanical efficiency despite their increased oxygen consumption. Therefore, some of the variability seen in efficiency in cyclists may be due to differences in the percentage of Type I muscle fibres (Coyle, Sidossis, Horowitz, & Beltz, 1992). However, as pedal rate is also a significant factor affecting pedal efficiency (Faria, 1995), muscular involvement (i.e. what muscles contribute in what capacity) throughout the pedal stroke might not be the main determinant of efficiency. While increases in pedal rate have been shown to lead to a decrease in economy and gross efficiency, higher cadences increase blood circulation and enhance venous return (E Faria et al., 2005).

Regardless of the mechanisms involved, it has been concluded that cycle training leads to continued neurological and/or muscular adaptations that reduce the overall demands of those recruited muscles (Coyle et al., 1988). By improving muscle conditioning and the motor patterns associated with cycling motion, cycling performance may be increased through improvements in efficiency and economy of motion. It is also evident that cycling performance could benefit from a cycling motion with an increased time of force application

throughout the pedal stroke. To date, however, interventions such as the clipless pedal have been unsuccessful at significantly modifying these recruitment patterns.

2.4.2 Summary

Muscular recruitment patterns that enhance efficiency and economy can have a large bearing on endurance cycling performance. Research to date has shown little-to-no benefits through the use of training with pedal clips and cleats on efficiency and economy of motion. As a result, researchers have looked at modifying other aspects of the foot/pedal interface, such as the pedal crank (Luttrell & Potteiger, 2003). The next section reviews the small number of studies that have used modified pedal cranks as a training tool to improve cycling performance.

2.5 Pedal Crank Innovations

Recent crank designs have attempted to enforce muscle recruitment patterns to encourage force throughout the entire 360° of the pedal revolution. One such design examined a crank prototype that involved a continuously changing crank circumference with regards to crank angle (Zamparo et al., 2002). The authors found significantly lower values for oxygen uptake and corresponding increases in efficiency at higher power outputs (250 W – 300 W) with the modified crank prototype compared with regular cranks (Zamparo et al., 2002). Another example of an innovative crank design is the Rotor which ensures each pedal is independent from the other (i.e. the cranks are not fixed at 180 degrees) (Santalla, Manzano, Perez, & Lucia, 2002). The authors found that when subjects cycled on the rotor cranks, delta efficiency was significantly higher than when the subjects cycled on regular cranks (Santalla et al., 2002). A newer crank design now available, similar to the rotor, is called PowerCranks™.

2.5.1 PowerCranks™

The use of PowerCranks™ (PowerCranks™, CA, USA) is claimed by the company to fully train the hip and knee flexors to facilitate an alteration in neuromuscular recruitment by recruiting muscles not predominately used in cycling. In doing so it may be possible to improve the overall efficiency of the pedal stroke (Luttrell & Potteiger, 2003).

Figure 5. The PowerCranks™ device.

When used during regular cycle training, PowerCranks™ ensure that each leg cycles in an independent circle motion by integrating a one-way clutch in each cycle crank arm. Hence, each leg drives the bicycle and one leg cannot assist the other, as is the case with regular cranks. This patented device claims to eliminate problems of inefficient cycling by eliminating the resistive forces produced during the recovery portion of the pedal stroke by making the cyclist pull up. When cyclists do not pull up with PowerCranks™, the crank will simply drop back down to bottom dead centre. In carrying out this motion during regular cycle training, the cyclist must learn the motor patterns associated with the assumed ideal cycling action. As a result, the cyclist may learn to pedal in circles.

A study by Luttrell and Potteiger (2003) compared a six week training period with PowerCranks™ or normal cranks (n = 6 per group). Subjects trained on a stationary bicycle

for 1-h a day, 3 days per week for 6 weeks. Testing took place before and after training and consisted of a graded exercise test and a 1-h submaximal ride. Measurements taken in the study included $\dot{V}O_2$max and ventilatory threshold during the graded exercise test, as well as heart rate, $\dot{V}O_2$, respiratory exchange ratio and gross efficiency during the 1-h submaximal ride. The authors found that training with PowerCranks™ resulted in a significantly lower heart rate and a significantly higher gross efficiency during the 1-h submaximal ride. However, no group differences were found for $\dot{V}O_2$max and ventilatory threshold.

While the study by Luttrell and Potteiger provides evidence to suggest that training with PowerCranks™ may increase gross efficiency, the sample size was small and the authors used only a limited number of physiological measurements. Although the authors suggested many adaptations and characteristics may have caused the observed increase in gross efficiency, they could not present firm conclusions due to methodological limitations. Moreover, EMG data were not measured in this study, so it is uncertain as to whether or not neuromuscular adaptations occurred. A study by Nuckles et al. (2007) examined the effects of 6-wks of PowerCranks™ training (consisting of randomly performed 5-min exercise bouts using PowerCranks™ and normal cranks) on the hip and knee flexors of eight subjects. The author's found that the iliopsoas and rectus femoris muscles displayed more activity (31% and 35% respectively) during the PowerCranks™ condition. However, the biceps femoris and gastrocnemius displayed no difference between conditions (Nuckles et al., 2007). Nevertheless, given the limited amount of studies examining the effectiveness of PowerCranks™ further research is required to examine how training with PowerCranks™ may induce positive cycle training adaptations that may lead to improvements in cycling performance.

2.6 Conclusion

Although the bicycle has developed from crude and dangerous origins to the sleekly designed machine that it is today, it is possible that aspects of the human-machine interaction are not as efficient as they possibly could be. Attempts to rectify this led to the introduction of toe clips and later pedal cleats. However, very little research has been published to show any benefits of improved cycling efficiency with clipless pedals. Despite the popularity of these devices, they appear to have little success at improving athlete's performances by reducing the resistive forces that occur during the recovery portion of the pedal stroke.

A device that could increase the efficiency of typical cycling technique may be of benefit to the competitive cyclist. In the pursuit of such a device, some inventors have more recently looked to the crank as a possible mechanism to increase the efficiency and economy of the cycling motion. One such device is called PowerCranks™. As of yet, there has been little research carried out on this device, making further research in this area necessary to determine whether training using an altered crank design can produce significant benefits to cyclist, particularly in the areas of muscular adaptations, economy of motion and cycling efficiency.

The purpose of this thesis, therefore, is to determine if training on PowerCranks™ will a) improve economy of motion, efficiency, oxygen uptake and power output at the ventilatory thresholds, and b) alter the activation rates of the lower limb muscles.

CHAPTER 3: METHODS

3.1 Participants

Sixteen trained male cyclists and triathletes were recruited for this study. They were required to have at least 3 years of cycling experience and a $\dot{V}O_{2max}$ of at least 55 $ml^{-1} \cdot kg^{-1} \cdot min$. Additionally, subjects were excluded from the study if they had any prior experience training with PowerCranks™. Subjects completed a medical and training history questionnaire prior to commencement of the study and were disqualified from the study if they were taking prescribed medications or suffering from a pre-existing injury. Subjects were asked to maintain a similar diet throughout the study and asked to avoid substances such as alcohol or caffeine in the 24-h period prior to testing. As well they were also given a food and drink questionnaire to ensure compliance of this request. All risks and benefits of participating in the study were clearly explained to the subjects, and written informed consent was obtained prior to participation. Prior to data collection, ethical approval was attained through the Human Research Ethics Committee of Edith Cowan University.

3.2 Design

The study consisted of a matched-group counterbalanced design, whereby subjects were allocated into one of two groups so that age, body mass and $\dot{V}O_{2max}$ levels were equally matched; that is, the aim was to have no significant differences in these variables between the groups prior to the start of the training interventions. The first group (PC; n = 8) trained with PowerCranks™ while the second group (NC; n = 8) trained with their normal bicycle crank arms.

Subjects first came into the laboratory to carry out a familiarisation session, which included an introduction to the equipment and a brief run-through of all testing and training

procedures. Subjects in the PC group then partook in pre-training testing on separate days, which included, 1) a graded exercise test, in which $\dot{V}O_{2max}$, ventilatory thresholds ($\dot{V}T_1$ and $\dot{V}T_2$), gross efficiency (GE) and economy of motion (EM) were determined; and 2) a PowerCranks™ efficiency and economy test (PowerCranks™ test, PCT). NC group subjects only completed the graded exercise test.

Subjects were allocated to the PC or NC training groups based on results from the preliminary testing sessions. Subjects assigned to the PC group participated in three familiarisation sessions using the PowerCranks™. Following this, all subjects began their training sessions using either PowerCranks™ or normal crank arms. The training portion of the study consisted of the subject's regular training program for a period of 5-wks. The number of training hours of the PC and NC groups was matched by asking NC group subjects to replicate the training hours of their equal in the PC group. The training was matched in terms of total hours, rather than kilometres, as total kilometres were expected to drop whilst subjects became accustomed to the new cranks.

Testing, identical to the pre-training tests, then followed in the week immediately after the 5-wk training intervention (see Figure 6). Prior to all testing sessions, subjects were asked to assess their recovery from the previous session on a scale and to also provide comments regarding their perception of their recovery. Likewise, at the end of each testing session, subjects were asked to assess the difficulty of their session on an RPE scale (sessional RPE) and to provide comments regarding their perception of the session (Day, McGuigan, Brice, & Foster, 2004). Subjects were tested in the 3-h post absorptive state (i.e. subjects had not eaten anything for the 3-h prior to testing) to ensure that values of efficiency and economy were not tainted (Spriet & Peters, 1998) and also to ensure that the subject's performance was not restricted by digestive processes. During all training and testing sessions, subjects were allowed to drink water *ad libitum*.

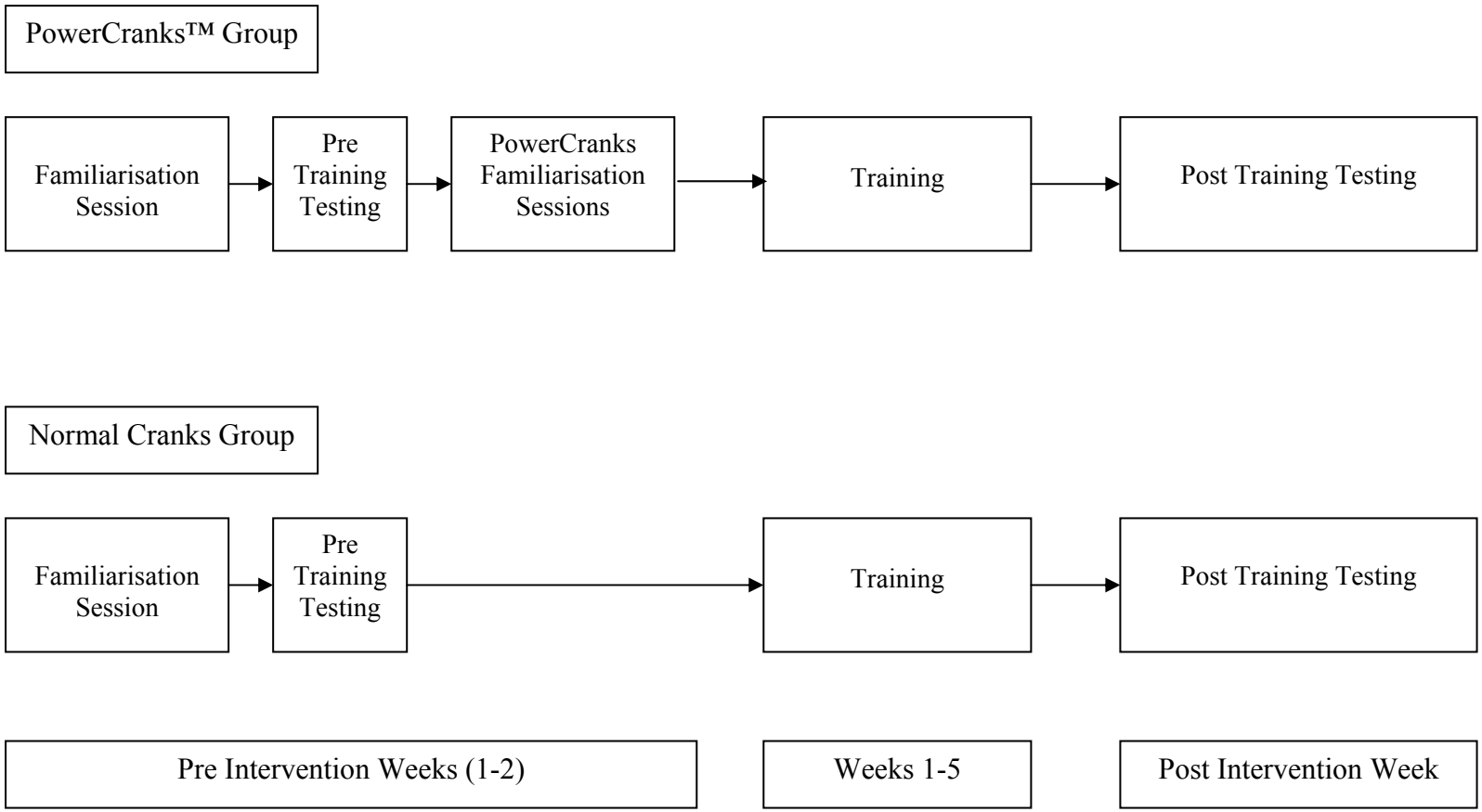

Figure 6. Study design.

3.3 Procedure

After subject screening and signing of the informed consent document, subjects reported to the laboratory for a familiarisation session in order to become further informed regarding specifics of the study's protocol, procedures and relevant equipment. Subjects also completed a 15-min cycling session so as to become accustomed to the Velotron cycle ergometer. Subsequent sessions consisted of a pre-training testing week that took place on one of two identically calibrated magnetically-braked cycle ergometers (Velotron, Elite, RacerMate, Seattle, WA, USA); one equipped with PowerCranks™ and one with normal crank arms. The length of both crank arm sets was 172.5 mm. Throughout all testing conditions, subjects were allowed to use their own pedals and cycling shoes. Testing occurred on two separate days, separated by at least 48-h, and consisted of 1) a graded exercise test, and 2) an efficiency and economy test (as described below).

Subjects allocated to the PC group then carried out three PowerCranks™ familiarisation sessions; one immediately before the efficiency and economy test, and the other two separated by at least 48-h each. These sessions, along with practice sessions on both a stationary bicycle and the subjects' own bicycle, consisted of verbal and written information about the technique required to pedal using the cranks. Subjects in both groups then began the training intervention using their allocated cranks and the subject's regular training program. Following the five weeks of training, post training testing took place, consisting of the graded exercise test, selected muscle measurements and for the PC group, the efficiency and economy test, as previously described.

3.3.1 Maximum Voluntary Isometric Contractions

Prior to the graded exercise test, the subject's maximal isometric strength of the hamstrings and quadriceps was determined using the Biodex System 3 (Biodex Medical Systems, Inc., New York, USA). To obtain measurements for the hamstrings and quadriceps, the subject's upper body was firmly strapped to the seat during testing whilst the left limb was attached to the arm of the dynamometer. Strength measurements were taken at 60^{o} for the hamstrings and quadriceps with the reference point being full extension, as adapted from previous studies (Hunter, Gibson, Lambert, & Noakes, 2002). The maximal isometric strength for the gastrocnemius was determined by sitting the subject in a calf raise machine with a block of wood under their feet to bring the angle of their ankle up to 90^{o}. At this stage, two muscle girth measurements were also taken. The first of these was the upper leg at the level of the rectus femoris electrode placement and the second was the lower leg at the level of the gastrocnemius electrode placement.

3.3.2 Graded Exercise Test

The graded exercise test (GXT) was conducted on a cycle ergometer and consisted of a slow ramp protocol whereby subjects began pedalling at 50 W, and increases of 50 W occurred every 4 min. Subjects cycled at a freely chosen cadence until volitional exhaustion or until they could not consistently maintain 60 $revs \cdot min^{-1}$, at which point the test was terminated.

Oxygen uptake, carbon dioxide production and minute ventilation were measured via a ParvoMedics metabolic cart (ParvoMedics, Salt Lake City, UT, USA). Prior to testing, the gas analysers were calibrated using gases of known concentrations, while the flow meter was calibrated using a Hans Ruldoph 3 L syringe over a range of flow rates. $\dot{V}O_{2max}$ was determined as the average of the highest 4 values. Ventilatory thresholds were determined using the methods of Lucia

et al. (2000) by which $\dot{V}T_1$ is defined as an increase in $\dot{V}E/\dot{V}O_2$ with no concomitant increase in $\dot{V}E/\dot{V}CO_2$ and $\dot{V}T_2$ is defined as an increase in both $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$.

Electromyography (EMG) was measured halfway through the 200 W stage of the GXT using the Data Logger ME3000 (Mega Electronics Ltd., Kuopio, Finland). For the measurement of EMG, silver/silver chloride surface electrodes of 20 mm in diameter were fixed to the belly of each of the three selected muscles of the left leg (identified below). Electrodes were placed 20 mm apart with all electrodes being positioned and aligned as suggested by the European Recommendations for Surface EMG (Hermens et al., 1999).

The selected muscles were the vastus lateralis, biceps femoris, and gastrocnemius (medialis). These muscles were chosen as they represented the predominant muscle used during typical cycling action (vastus lateralis) and two that may increase in activation as a result of the training intervention (biceps femoris and gastrocnemius). Preparation of the skin prior to electrode placement consisted of shaving the area, followed by light abrasion and wiping the area with an alcohol wipe. Following this, electrodes were placed and a reading of less than 5 kΩ achievable through skin impedance was deemed as acceptable. Electrodes were held in place using a hypoallergenic polyacrylate adhesive tape (Fixomull) to ensure minimal movement throughout testing (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002).

A digital electromagnetic switch was securely fitted to the bicycle frame at top dead centre and a magnetic sensor was also fitted to the crank arm for standardisation of the EMG data. The switch produced a digital signal (± 10 V) when the crank arm reached top dead centre.

EMG data were collected from the subjects in the seated position for ten seconds mid-way through the 200W stage. EMG data from five continuous crank

revolutions was used to calculate integrated EMG (iEMG). With the use of LabVIEW graphical development software (version 6.1; National Instruments Corporation, Austin, TX), raw EMG data were full-wave rectified, and passed through a high-pass fourth order Butterworth filter (cut-off frequency of 15 Hz) to remove movement artefact. EMG data were then smoothed with a low-pass fourth order Butterworth filter (cut-off frequency of 5 Hz) to produce a linear envelope (Lepers et al., 2002; Tucker, Raunch, Harley, & Noakes, 2004). An ensemble average was generated from the five crank revolutions taken from time normalised data (0-1000 points for BDC to BDC) to reduce within subject variability. EMG data were amplitude normalised using the MVICs. The MVIC value was determined as the greatest value for an averaged 200-ms window of the linear envelope. The greatest EMG value for any of the three MVIC trials was used for normalisation purposes. An iEMG value at each data point was taken as the average of all time-series values in the ensemble average.

Ratings of perceived exertion were also taken following the completion of each stage using a 15 (6-20) point Borg scale (Borg, 1970). Heart rate was measured using a Polar heart rate monitor (Polar Electro, Kempele, Finland) with data being recorded and averaged over 15 s increments.

Economy of motion (EOM) was calculated by averaging the last two minutes of the 200 W stage and applying the following formula (Moseley & Jeukendrup, 2001) to each:

$$\text{EOM (W/L)} = \text{power output} / \dot{V}O_2$$

Gross efficiency (GE) was determined by averaging the data collected over the last two minutes of the 200 W workload (i.e. RER <1.00), and applying the following formula (Moseley & Jeukendrup, 2001):

GE (%) = [work rate (W) / energy expended ($J \cdot s^{-1}$)] x 100

Energy expenditure was determined by the following formula (Moseley & Jeukendrup, 2001):

Energy Expenditure ($J \cdot s^{-1}$) = [(3.869 x $\dot{V}O_2$) + (1.195 x $\dot{V}CO_2$)] x (4.186/60) x 1000

Peak power output (PPO) was recorded as the highest power output completed during the GXT. If a subject finished part way through a 4-min stage, PPO was calculated in a pro-rata manner using the following equation:

PPO = Wcom + [(t/4) x 50]

where Wcom is the power corresponding to the highest stage completed and t refers to the amount of time (min) completed during the unfinished stage (Hawley & Noakes, 1992).

3.3.3 PowerCranks™ Test

Gross Efficiency and Economy on the PowerCranks™ was measured (for PC group only) using the PowerCranks™ equipped Velotron. Subjects commenced pedalling at 50 W, and 50 W increases in power output occurred every 4 minutes until 4 stages were completed. Throughout this process, $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}E$ were measured using a Parvomedics metabolic cart (ParvoMedics, Salt Lake City, UT, USA). Heart rate and EMG were also measured as during the GXT.

3.3.4 Training Programme

The training programs of each subject were kept as similar as possible to their regular training volume and intensity so as to obtain an accurate gauge as to the effectiveness of training with PowerCranks™ in a realistic training situation. To ensure no significant changes in volume and intensity occurred between the two groups, each PC group cyclist was matched with a normal crank group subject that cycled a similar weekly distance and had a similar fitness level ($\dot{V}O_2max$). The PC group subject then commenced training at least 3-wks before their matched normal crank subject counterpart. Regular contact, in the form of phone calls and a detailed training diary between the investigator and PowerCranks™ subject was then carried out. The normal crank subject then received information about the matched PC group subject's training and was given instructions with regards to how much training they would do. This was based on a percentage of their regular training depending on what their matched PC group subject carried out for their training in that given week. Hence irrespective of group, each subject maintained similar training loads relative to their normal training programme and also in relation to their matched subject.

3.4 Statistical Analysis

A two-way repeated measures ANOVA (group x time) was used to contrast the groups over time, whilst a one-way ANOVA was used to compare dependant measures for within group comparison. All data are presented as means and standard deviations and significance was accepted at an alpha level of 0.05 for all tests.

Effect Size calculations were also used for selected measures to compare changes in dependent measures for within trial comparisons. All data was then given a magnitude derived from Table 1 with subjects classed as being recreationally trained.

Table 1. Scale for determining the magnitude of effect sizes in strength training research (adapted from Rhea, 2004).

Magnitude	Untrained	Recreationally Trained	Highly Trained
Trivial	<0.50	<0.35	<0.25
Small	0.50-1.25	0.35-0.80	0.25-0.50
Moderate	1.25-1.9	0.80-1.50	0.50-1.0
Large	>2.0	>1.5	>1.0

CHAPTER 4: LIMITATIONS AND DELIMITATIONS

4.1 Limitations

The apparent limitations of the study were as follows:

I. Cycling out of laboratory settings made the matching of individual subject training not as precise as was desired, as factors such as weather conditions may have altered training practices.
II. Subjects do not train consistently from week-to-week.
III. Cyclists by nature respond to training at different rates.
IV. The PowerCranks™ were attached to the subjects' own bicycle, hence the exact tracking of training outputs was difficult.

4.2 Delimitations

The imposed delimitations of this study were as follows:

I. Subjects only used the PowerCranks™ for a period of five weeks and therefore were not exposed to the training stimulus for a prolonged duration.
II. Subjects were only moderately-trained and well-trained, not elite cyclists therefore the findings of this study cannot be translated to elite cyclists.
III. Only Male subjects were accepted therefore the findings of this study may not translate to female cyclists.

CHAPTER 5: RESULTS

5.1 Subject Characteristics

The subject characteristics of each group are presented in Table 2 and indicate that individuals were trained cyclists as per Jeukendrup, Craig and Hawley's (2000) classifications. The groups were equally matched for age, height, body mass, fitness and training volume, as demonstrated by the fact that there were no significant differences in these variables between the groups.

Table 2. Subject characteristics

	Normal Cranks (n = 8)		PowerCranks™ (n = 8)	
	Mean	SD	Mean	SD
Age (years)	32.8	7.1	32.3	7.8
Height (cm)	181.8	7.0	176.1	7.8
Body Mass (kg)	77.4	6.7	75.1	6.1
$\dot{V}O_{2max}$ ($ml^{-1} \cdot kg^{-1} \cdot min$)	57.2	3.6	59.4	3.7
Distance cycled per week (km)	217	66	204	57
Duration of cycling per week (h)	7.1	2.7	6.8	2.3

Note. There were no significant differences between groups in these variables.

P values for all data are reported in a summary table in the appendix.

5.2 Economy and Efficiency for PowerCranks™ Group vs. Normal Cranks Group on Normal Cranks

There were no significant differences (i.e. p >0.5) in the variables of cycling economy and efficiency between the pre- and post-training time points for the PC group on normal cranks. However, following training there was a moderate effect size for both economy (0.93) and efficiency (0.90) in the PC group. In the NC group, economy and efficiency significantly decreased from pre- to post-testing using normal cranks, with a large effect size for economy (-1.59) and a moderate effect size for efficiency (-1.36). Furthermore, the NC group possessed significantly higher cycling economy and efficiency values than the PC group at the pre-testing time point. However, there were no differences between the PC and NC group in terms of the absolute values of these variables at the post-testing time point. This resulted in a significant interaction between the groups over time (Mean ± SD values can be seen in Figure 7).

5.2.1 Economy and Efficiency for PowerCranks™ Group on Normal Cranks vs. PowerCranks™ Group on PowerCranks™

Subjects in the PC group cycling on normal cranks (PC on Normal Cranks) had significantly higher values of economy and efficiency at the pre-testing time point compared to when they were cycling on PowerCranks™ (PC on PowerCranks™). However, no significant differences in these variables were found between the pre- and post-testing time points in the PC group. The difference in these variables between PC on Normal Cranks and PC on PowerCranks™ remained consistent following the 5-wk training period (Mean ± SD values can be seen in Figure 7).

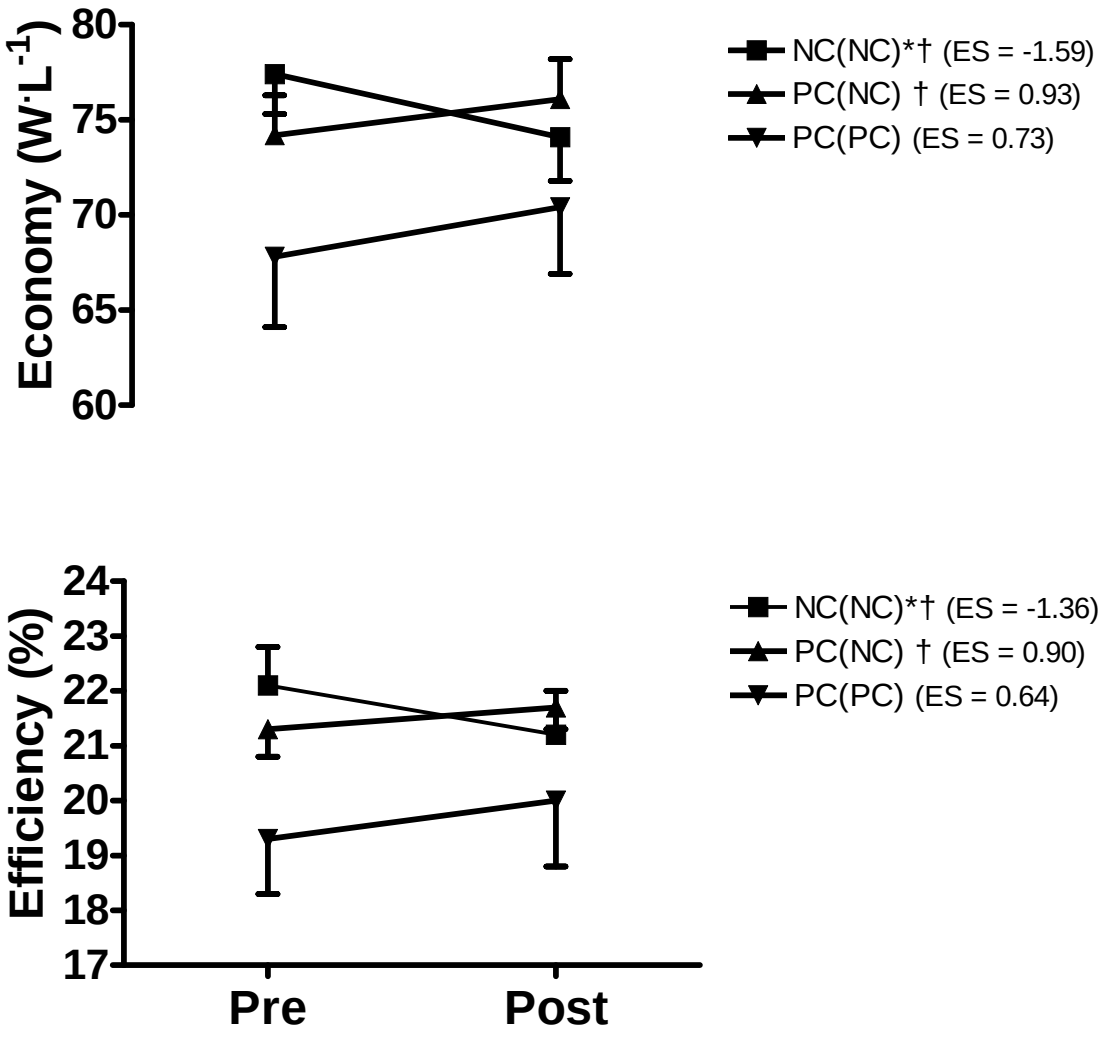

Figure 7. Pre- and post-study variables of gross efficiency and economy for the normal cranks and PowerCranks™ groups for the graded exercise test and PowerCranks™ test at 200W.

*Note. Values are means ± standard deviations (error bars); * denotes significance (pre to post; one-way ANOVA, p <0.05) and † denotes significance (treatment by time; two-way ANOVA, p <0.05). ES = Effect Size.*

5.3 Integrated Electromyography and Muscle Circumference

5.3.1 Integrated Electromyography

There were no significant changes in the iEMG of the Vastus Lateralis, Biceps Femoris and Gastrocnemius from the pre- to post-testing time points for either the NC or PC groups during the GXT. Neither were there any significant changes between pre- and post-testing values for PC group subjects cycling on PowerCranks™ during the PCT (Mean ± SD values can be are presented in Table 3).

Table 3. Pre- and post-study variables of muscle activation for the normal cranks and PowerCranks™ groups during the graded exercise test and PowerCranks™ group during the PowerCranks™ test.

	Normal Cranks group (GXT)		PowerCranks™ group (GXT)		PowerCranks™ group (PCT)	
Location of iEMG	Pre	Post	Pre	Post	Pre	Post
VL (%MVIC)	11.3 ± 3.3	12.5 ± 3.8	11.6 ± 2.7	12.7 ± 5.8	9.8 ± 3.3	12.4 ± 6.1
BF (%MVIC)	9.9 ± 4.8	11.0 ± 3.1	10.8 ± 6.1	9.4 ± 3.4	16.1 ± 6.3	13.8 ± 7.7
GAS (%MVIC)	23.1 ± 10.1	21.4 ± 7.7	26.5 ± 7.6	21.8 ± 6.3	29.3 ± 9.6	28.0 ± 6.0

Note. Values are means ± standard deviations. iEMG = Integrated Electromyography, VL = Vastus Lateralis, BF = Biceps Femoris, GAS = Gastrocnemius, MVIC = maximum voluntary isometric contraction. GXT = graded exercise test, PCT = PowerCranks™ Test.

5.3.2 Muscle Circumference

There was no significant change in the upper and lower muscle girths for either group from pre- to post-testing (Mean ± SD values can be seen in Table 4).

Table 4. Pre- and post-study variables of upper and lower leg muscle girths for the normal cranks and PowerCranks™ groups.

	Normal Cranks group (GXT)		PowerCranks™ group (GXT)	
Location of Girth Measurement	Pre	Post	Pre	Post
Upper leg (cm)	56.1 ± 1.5	56.0 ± 1.8	56.0 ± 2.0	56.3 ± 1.8
Lower leg (cm)	38.0 ± 2.2	37.6 ± 2.1	36.8 ± 1.8	36.9 ± 1.4

Note. Values are means ± standard deviations. Upper = upper leg circumference at 50% of thigh length, Lower = lower leg circumference at the point of maximum girth, cm = centimeters. GXT = graded exercise test, PCT = PowerCranks™ Test.

5.4 Oxygen Uptake, Thresholds, Cadence and Power Outputs

No significant differences in $\dot{V}O_2$max or Peak Power Output (PPO) existed between groups. Likewise there were no significant differences in $\dot{V}O_2$max or PPO for either the NC or PC groups from pre- to post-testing. The $\dot{V}O_2$ and power output at $\dot{V}T_1$ and $\dot{V}T_2$, expressed both as an absolute value and as a percentage of its maximum, showed no significant change from the pre- to post-testing time points for either the NC or PC groups. As well, there were no significant differences in these variables between groups (Mean ± SD values can be seen in Table 5).

Table 5. Pre- and post-study variables of maximal oxygen uptake, peak power output as well as the first and second ventilatory thresholds for the normal cranks and PowerCranks™ groups during the graded exercise test.

	Normal Cranks		PowerCranks™	
	Pre	Post	Pre	Post
$\dot{V}O_{2max}$ ($ml^{-1}\cdot kg^{-1}\cdot min$)	57.2 ± 3.6	58.6 ± 3.1	59.4 ± 3.7	58.3 ± 5.8
PPO (W)	372 ± 31	371 ± 35	370 ± 26	369 ± 34
$\dot{V}T_1$ (%VO_2max)	64 ± 8	61 ± 10	63 ± 5	62 ± 6
$\dot{V}T_2$ (%VO_2max)	82 ± 8	83 ± 9	87 ± 5	85 ± 5
$\dot{V}T_1$ VO_2 ($L\cdot min^{-1}$)	2.8 ± 0.5	2.7 ± 0.5	2.9 ± 0.3	2.7 ± 0.2
$\dot{V}T_2$ VO_2 ($L\cdot min^{-1}$)	3.6 ± 0.6	3.7 ± 0.4	3.9 ± 0.4	3.7 ± 0.5
$\dot{V}T_1$ PO (%PPO)	65 ± 8	61 ± 9	62 ± 5	63 ± 4
$\dot{V}T_2$ PO (%PPO)	84 ± 6	84 ± 7	88 ± 2	86 ± 3
$\dot{V}T_1$ PO (W)	243 ± 37	228 ± 37	234 ± 26	233 ± 24
$\dot{V}T_2$ PO (W)	313 ± 35	310 ± 37	330 ± 24	319 ± 37

Note. Values are means ± standard deviations. $\dot{V}O_2$ = oxygen consumption, PO = power output. No differences between groups or over time.

No significant differences in pedalling rate at 200 W were found from pre- to post-training in either group during the GXT (NC, Pre: 96 ± 3 $revs\cdot min^{-1}$, Post: 97 ± 2 $revs\cdot min^{-1}$; PC, Pre: 94 ± 7 $revs\cdot min^{-1}$, Post: 90 ± 9 $revs\cdot min^{-1}$). However there was a significant difference in cadence found for the PC group during the PCT with PC group subjects displaying an increased cadence in the post PCT session (Pre: 79 ± 5 $revs\cdot min^{-1}$, Post: 92 ± 9 $revs\cdot min^{-1}$).

5.5 Heart Rate and RPE

There were no significant changes over time in the heart rate or RPE at 200 W or the Sessional RPE for either the NC or PC groups (Mean ± SD values can be seen in Table 6).

Table 6. Pre- and post-study variables of heart rate (200 W level), RPE (200 W level) and sessional RPE for the normal cranks and PowerCranks™ groups during the graded exercise test and PowerCranks™ test.

	Normal Cranks group (GXT)		PowerCranks™ group (GXT)		PowerCranks™ group (PCT)	
	Pre	Post	Pre	Post	Pre	Post
Heart Rate (bpm)	140 ± 13	141 ± 8	143 ± 15	143 ± 16	151 ± 16.2	150 ± 13.1
RPE	10 ± 1	10 ± 2	10 ± 2	12 ± 1	N/A	N/A
Sessional RPE	17 ± 3	16 ± 2	15 ± 1	16 ± 2	16 ± 1	16 ± 3

Note. Values are means ± standard deviations. bpm = beats per minute, RPE = rating of perceived exertion; 6-20 scale (Borg, 1970).

CHAPTER 6: DISCUSSION

The purpose of this study was to determine whether or not training with PowerCranks™ for 5 weeks would alter cycling economy and efficiency, $\dot{V}O_2max$, ventilatory thresholds and/or muscle activation rates compared to a group that trained at a similar level using their regular cranks. The main findings were that training on PowerCranks™ did not improve economy, efficiency or muscle activation patterns when cycling on both PowerCranks™ and regular cranks. These findings will be elaborated on in the following section.

6.1 Economy and Efficiency

The most important finding of this study was that there was no significant improvement in economy or efficiency for the PC group on PowerCranks™ from pre- to post-training testing time points. Likewise, there was no significant improvement in economy or efficiency on normal cranks for either group from pre- to post-testing periods. PC group subjects cycling on PowerCranks™ were also less economical and efficient compared to when they were cycling on normal cranks. Only one other published study has examined the influence of PowerCranks™ training on cycling efficiency parameters (Luttrell & Potteiger, 2003). In this study, Luttrell and Potteiger (2003) examined the effects of training with PowerCranks™ for 6 weeks on cycling efficiency during a 60 min submaximal ride at the power output corresponding to 69% of pre-training $\dot{V}O_{2max}$. Values of gross efficiency were significantly greater in the PowerCranks™ groups compared to the control group at the 45 min and 60 min time points. However, it is uncertain as to whether or not the improvement in efficiency shown with PC training would have translated into an improvement in endurance cycling performance. Nevertheless, the authors of this

study found that PowerCranks™ training induced physiological adaptations that reduced energy expenditure during a 60 min submaximal ride. In contrast, despite similar fitness levels and training time periods between our study and that of Luttrell and Potteiger's (2003), results of the current study showed no such improvements in efficiency. One notable difference between the studies is the location of the training sessions. Participants in Luttrell and Potteiger's study trained on a stationary ergometer in the laboratory, whilst participants in the current study trained on the road. Perhaps these different training modes (i.e. stationary versus field bicycle training) may have contributed to the disparate study findings. Subjects training on their own bicycle may have experienced a reduction in training initially whilst they became accustomed to riding on their cranks, due to factors such as safety and stability. Nevertheless, there were no significant differences in total training time or total training kilometres between the NC and PC groups in the current study. Also, during testing sessional RPE measures showed that the subjects' perceived the testing to be equally as difficult during both the pre- and post-testing time measurement points. Heart rate was not different between testing time-points. Hence, it is unlikely that training duration or intensity differences between groups would have impacted the results. While it is known that differences in cycling cadence can affect economy (Marsh, Martin, & Foley, 2000), the only significant change seen in cycling cadence in the current study was when the PowerCranks™ group cycling on PowerCranks™ achieved a significantly greater cadence during the PCT from pre- to post-testing time-points. Hence, we could not detect a change in cycling economy with PowerCranks™ training in the current study.

The finding of a reduced cycling economy and efficiency in the normal crank training group (that resulted in a significant group interaction over time) is difficult to explain. A possible reason for this could be participants not adhering to requests to be 3-hrs in the post absorptive state before testing, which would influence the

subjects respiratory exchange ratio and hence values of efficiency. The majority of testing for the NC group was also carried out in the winter months, which could have resulted in a reduced quality of training due to the higher frequency of inclement weather days that are more commonly experienced during this period. The majority of the PC group training program was carried out in the summer months, where athletes would have been more inclined to train. Nevertheless, the total cycle training distance and time spent cycling was the same for both groups, leaving explanations for this reduction in economy and efficiency unclear. Regardless, results from the present study suggest that it is unlikely that 5-wks of training with PowerCranks™ will positively alter cycling economy and/or efficiency.

6.2 Muscle Activation

As was the case for cycling economy and efficiency, there was no significant change from pre- to post-testing time measurement points for the level of muscle activation measured at each of the three sites for the PC group training on PowerCranks™. Likewise, even when groups were riding on normal cranks, there was no difference in the level of muscle activation at each of the three measurement sites between the pre- and post-testing time points (Table 3).

Coyle, Coggan, Hopper and Walters (1988) suggest that in the absence of increases in $\dot{V}O_{2max}$, improvements in performance may be related to neuromuscular adaptations in the trained skeletal muscle. These improvements may be things such as muscle fibre recruitment, firing rate, and motor unit synchronisation (Enoka, 1997; Kraemer, Fleck, & Evans, 1996). Hence, even in the absence of significant changes to efficiency, economy and $\dot{V}O_2$ inside of 5-wks, changes in muscle activation patterns and electromyography may still be detected (Creer et al., 2004;

Sale, 1988). For example, Creer et al. (2004) demonstrated in a group of 17 trained cyclists that four weeks of sprint cycle training (carried out bi-weekly comprising a total of 28 min of the training period) was sufficient to increase motor unit activation, again suggesting that the 5-wk training block used in the present study should have elicited a response in this variable. However, this was not the case and may indicate that the PowerCranks™ do not change activation patterns when returning to regular cranks. Bertucci, Grappe and Groslambert (2007) showed that crank torque profiles of a laboratory-based ergometer were significantly different than field road cycling conditions. Thus, it is possible that changes found in laboratory-based tests with training may not be apparent in road cycling conditions, and vice versa. The principal of specificity states that in order to provoke adequate physiological adaptations, specific tasks need to be completed under specific conditions (Basset & Boulay, 2003). Therefore, it is possible that Luttrell and Potteiger's (2003) findings resulted because of the fact that the training was specifically done in the laboratory, as was the testing. In the current study, the training was completed on the subject's own bicycle, with testing completed in the laboratory. Because differences may exist between indoor laboratory riding and outdoor field cycling (Bertucci et al., 2007), this could have altered learned muscle recruitment patterns and their associated testing response. It is possible that had the training in the current study been completed specifically in the laboratory, that we may have found similar results to those found by Luttrell and Potteiger (2003). However, our findings could also suggest that training with PowerCranks™ may only be effective when the training is completed indoors. Further, had we been able to test our subjects in the field, we again may have been able to detect the specific influence of the field PowerCranks™ training.

It is evident that a relationship exists between effective pedal force and cycling economy (Candotti et al., 2007). Thus, a device that can increase the effective force

applied to the pedals should in theory improve cycling economy. PowerCranks™ have been designed to train cyclists to apply more force during the upstroke of the pedal cycle because this is commonly where the least amount of force is generated during the pedalling action. Thus, PowerCranks™ may improve effective force and economy by increasing the force generated during the upstroke. A recently unpublished report (conference abstract) by Nuckles et al. (2007) found 31% and 35% more activity in the iliopsoas muscle and rectus femoris muscles, respectively, after 6 weeks of training on PowerCranks™. The current study showed no such increase in rectus femoris activation. The findings by Nuckles et al. (2007) are similar to the present study with respect to the fact that they found no change in biceps femoris and lateral gastrocnemius muscles activation following PowerCranks™ training. This finding is interesting, as the manufactures of PowerCranks™ claim that the hamstrings muscles will be the muscle group most influenced by training on PowerCranks™. A problem with the Nuckles et al (2007) study design, however, was that it did not compare results to baseline training levels, but instead used a cross-sectional analysis examining each cyclist's performance on PowerCranks™ and normal cranks. Hence, the authors could not confirm whether or not these increases in muscles activation rates actually lead to improvements in cycling performance. As noted by Broker and Gregor (1996), the "ineffective" force, as it is often called, could be misleading, as reducing the resistive forces associated with the downward phase of the pedal motion would more than likely require more muscular work without any concurrent increases in cycling power. Therefore, it is possible that the "normal' cycling action is in fact the optimal technique given the biomechanical structure of the human body. Thus, no matter how much training a person does to change this, they may, more often than not, return to these "normal" patterns upon return to normal cranks. . This possibility was confirmed in a recent study by Bohm, Siebert and Walsh (2008). They showed that although 5-wks of PC

training significantly reduced work completed in the downward sector of the pedal stroke, there was an increase in work in the other sectors of the pedalling cycle resulting in the same power output. This confirms the study by Broker and Gregor (1996), which found that there was significantly reduced work completed in the downward sector of the pedal stroke when compared to the control group subjects; however this was compensated for by the other sectors (i.e. the other sectors involved more work) to obtain the same effect on power output.

One limitation to the findings of the current study is that EMG data were summed over the entire pedal stroke. Had we been able to complete a more thorough examination of the pedal stroke, using techniques such as quadrant analysis, we may have been able to see where the muscles were becoming more or less activated. Indeed, quadrant analysis can examine where force is being applied during the pedal stroke by breaking the pedal stroke into four equal independent quadrants (Eisner, Bode, Nyland, & Caborn, 1999). Such an analysis would have been able to indicate whether training with PowerCranks™ may have altered the activation during of certain quadrants of the pedal stroke, despite a similar level of summed muscle activation. In any case, it is important to note that reducing the resistive forces associated with the upward phase of the pedal motion may require more muscular work without a concurrent increase in cycling power output, hence negating the use of PowerCranks™ (Broker & Gregor, 1996).

Another problem with the collection of the EMG data was that the maximal voluntary isometric contractions seemed to vary considerably for the calf muscle measurement. Hence, it is evident that even if there was no change in activation whilst cycling, the percentage of maximum may have been different. There is very little literature looking specifically at how iEMG is altered with exercise training (i.e. over a prolonged duration rather than just a single testing time point), so this variability makes it difficult to draw strong conclusions from the current data (Jones

& Polland, 2001, p. 59). Jones and Polland (2001, p. 59) note that in some cases, iEMG has been shown to increase significantly in response to strength training, particularly in the first 3-4 weeks. Furthermore Hakkinen and Komi (1983) found that changes in iEMG closely mimicked changes in force production over a 16 week training program and subsequent 8 week detraining program. It is however evident that EMG might not be altered with training due to technical problems involved with making repeated EMG measurements (Narici et al., 1996). Nevertheless, Laplaud, Hug, Grelot (2005) note there is a high level of reproducibility with regards to the EMG activity level of the lower limb muscles during a graded exercise test. Mirka (1991) suggests that inaccuracies will result when an unrestricted dynamic task, such as cycling, is normalised to a single MVIC performed at one reference point. Creer et al. (2004) adds to this by suggesting that the collection of EMG should be performed in a manner that specifically mimics the activity under analysis, in order to assess the adaptations that may take place. Whilst the current study attempted to do this, it may be that the calf MVIC measurement for which the value was compared to was not sufficient to produce a reliable value. Regardless, the other two muscles investigated also showed no significant improvements in muscle activation. As a result, we can only conclude that 5-wks of training with PowerCranks™ did not alter the level of activity of the muscles we measured.

There is no doubt from the literature that improvements in cycling technique lead to improvements in cycling economy (Candotti et al., 2007). The conjecture lies in whether or not PowerCranks™ produce an improvement in cycling technique that is correlated to improvements in cycling economy and efficiency and hence cycling performance. If PowerCranks™ are expected to positively change muscle activation patterns, this must be done in such as way that produces a lower O_2 cost at a given power output. Because neither of these changes occurred in the current study, we must conclude that PowerCranks™ did not provide any significant benefits to

cycling economy after 5-wks of training. If changes in muscle activation did not occur, and cycling economy was not altered, it is unlikely that neuromuscular adaptations occurred that would have improved cycling performance. However, the current study did not measure cycling performance, making it unclear as to whether any such improvements would have occurred. Future research should examine the influence of training with PowerCranks™ on cycling performance.

6.3 Oxygen Consumption, Peak Power Output and Ventilatory Thresholds

The current study also showed no significant changes in a range of other variables that are commonly associated with cycling performance (E Faria, D Parker, & I Faria, 2005). $\dot{V}O_2$max, ventilatory thresholds and peak power output did not change over time in either group, nor were there differences between the groups in these variables (Table 5). These findings are similar to those of Luttrell and Potteiger (2003), who also found no change in $\dot{V}O_2$max or the $\dot{V}$T (as measured by the V-slope method) and also Bohm et al. (2008) who found no significant difference for peak power and power output at $\dot{V}$T.

$\dot{V}O_{2max}$ and peak power output are two common predictors of endurance performance. Mujika and Padilla (2001) state that it is sometimes hard to draw comparisons between differing protocols when using $\dot{V}O_{2max,}$ however when combined with power output data real performance improvements in either of these variables are meaningful and suggest that performance will be enhanced. Peak power output has been shown to be an accessible and valid predictor of completion time for 20 km time trials (Hawley & Noakes, 1992) and average power output performed during a 16.1 km time trial (Balmer, Davison, & Bird, 2000). Paton and

Hopkins (2001) also state that the peak power obtained during an incremental test has the lowest random error and provides a reliable measure of tracking performance. Given this, had training with PowerCranks™ elicited an improvement in cycling performance, these variables should have shown some noticeable increase over the 5-wk training duration in the current study. Again however, this was not the case, suggesting that training with PowerCranks™ in the field had little effect on the key parameters that influence cycling performance over a 5-wk period.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions and Practical Implications

This study has shown that five weeks of training with PowerCranks™ produced no significant improvement in physiological and performance-related variables measured on both PowerCranks™ and on regular cranks, when compared to a control group measured on regular cranks. Training with PowerCranks™ elicited no significant improvements in cycling economy or efficiency, oxygen uptake, ventilatory thresholds, power outputs or levels of muscle activation compared to a control group training on normal cranks.

The main limitation of this study was that it only examined the initial adaptations to PowerCranks™ training over a five week period. Indeed, this device has not been extensively researched thus far and further research is needed to determine if PowerCranks™ do provide a benefit to not only cyclists but also to runners and those involved in run-based based sports due to the focus on training of the hip flexor muscles. Further research is also needed to determine if the PowerCranks™ training is best completed in the field (i.e. mounted to the cyclists bicycle) or on stationary bicycles in controlled and structured technique sessions. Further studies should also examine the influence of PowerCranks™ training on cycling performance, using either a time trial or a time-to-exhaustion test.

In conclusion, results from this study do not support benefits claimed by PowerCranks™. However, further research is needed to examine the influence of training with PowerCranks™ on various physiological variables and cycling performance over a more prolonged training duration.

7.2 Recommendations for Further Research

PowerCranks™ only look at one aspect of cycling performance. Thus, it may be prudent to recommend that cyclists maintain training on regular cranks during outdoor training. However, when on an indoor stationary bicycle, using the cranks as additional training or as a substitute for weight training could be helpful. As noted earlier, other studies using structured lab-based training sessions have shown significant effects (Luttrell & Potteiger, 2003). Future studies are needed to further examine the implications of training with PowerCranks™ with regards to a longer training time frame, and possibly either longer, more frequent, or more intense training sessions. Other areas not yet explored with regards to the potential that PowerCranks™ training could have on athletic performance include the ability to run after the cycling leg of multi-sport events.

CHAPTER 8: REFERENCES

Balmer, J., Davison, R., & Bird, S. (2000). Peak power predicts performance power during an outdoor 16.1km cycling time trial. *Medicine and Science in Sports and Exercise, 32*(8), 1485-1490.

Basset, F., & Boulay, M. (2003). Treadmill and cycle ergometer tests are interchangeable to monitor triathletes annual training. *Journal of Sports Science and Medicine, 2*, 110-116.

Bertucci, W., Grappe, F., & Groslambert, A. (2007). Laboratory versus outdoor cycling conditions: differences in pedaling biomechanics. *Journal of Applied Biomechanics, 23*, 87-92.

Bohm, H., Siebert, S., & Walsh, M. (2008). Effects of short-term training using SmartCranks on cycle work distribution and power output during cycling. *European Journal of Applied Physiology*.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine, 2*(2), 92-98.

Broker, J., & Gregor, R. (1996). Cycling biomechanics. In E. Burke (Ed.), *High-Tech Cycling*. Champaign, IL: Human Kinetics.

Candotti, C., Ribeiro, J., Soares, D., Oliveira, A., Loss, J., & Guimares, A. (2007). Effective force and economy of triathletes and cyclists. *Sports Biomechanics, 6*(1), 31-43.

Capmal, S., & Vandewalle, H. (1997). Torque velocity relationship during cycle ergometer sprints with and without toe clips. *European Journal of Applied Physiology, 76*, 375-379.

Coyle, E., Coggan, A., Hopper, M., & Walters, T. (1988). Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology, 64*(6), 2622-2630.

Coyle, E., Feltner, M., Kautz, S., Hamilton, M., Montain, S., Baylor, A., et al. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine and Science in Sports and Exercise, 23*(1), 93-107.

Coyle, E., Sidossis, L., Horowitz, J., & Beltz, J. (1992). Cycling efficiency is related to the percentage of type I muscle fibres. *Medicine and Science in Sports and Exercise, 24*(7), 782-788.

Creer, A., Ricard, M., Conlee, R., Hoyt, G., & Parcell, A. (2004). Neural, metabolic, and performance adaptations to four weeks of high intensity sprint interval

training in trained cyclists. *International Journal of Sports Medicine, 25*, 92-98.

Day, M., McGuigan, M., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance training using the session RPE scale. *Journal of Strength and Conditioning Research, 18*(2), 353-358.

Dietz, V. (1997). Neurophysiology of gait disorders: present and future applications. *Electroencephalography Clinical Neurophysiology, 103*(3), 333-355.

Duc, S., Betik, A. C., & Grappe, F. (2005). EMG activity does not change during a time trial in competitive cyclists. *International Journal of Sports Medicine 26*, 145-150.

Eisner, W., Bode, S., Nyland, J., & Caborn, D. (1999). Electromyographical timing analysis of forward and backward cycling. *Medicine and Science in Sports and Exercise, 31*(3), 449-455.

Enoka, R. (1997). Neural adaptations with chronic physical activity. *Journal of Biomechanics, 30*(5), 447-455.

Evangelisti, M., Moser, C., Kuesel, L., Verde, T., & Miles, D. (1999). Effect of clipless pedal use during cycle ergometry on physiological parameters in well trained subjects. *Medicine and Science in Sports and Exercise, 31*(5), S259.

Faria, E. (1992). Energy expenditure, aerodynamics and medical problems in cycling. An update. *Sports Medicine, 14*(1), 43-63.

Faria, E., Parker, D., & Faria, I. (2005). The science of cycling factors effecting performance -part 2 *Sports Medicine, 35*(4), 313-337.

Faria, E., Parker, D., & Faria, I. (2005). The science of cycling physiology and training - part 1. *Sports Medicine, 35*(4), 285-312.

Faria, I. (1995). Cycling: Physiology and Training. In T. Fahey (Ed.), *Encyclopaedia of Sports Medicine and Exercise Physiology*. New York: Garland.

Hakkinen, K., & Komi, P. (1983). Electromyographic changes during strength training and detraining. *Medicine and Science in Sports and Exercise, 15*(6), 455-460.

Hawley, J., & Noakes, T. (1992). Peak power output predicts maximal oxygen uptake and performance in trained cyclists. *European Journal of Applied Physiology, 65*, 79-83.

Hermens, H., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., et al. (1999). *European Recommendations for Surface Electromyography*. Netherlands: Roessingh Research and Development.

Hoes, M., Binkhorst, R., Smeekes-Kuyl, A., & Vissers, A. (1968). Measurement of forces exerted on pedal and crank during work on a bicycle ergometer at different loads. *European Journal of Applied Physiology, 26*(1), 33-42.

Hunter, A., Gibson, A., Lambert, M., & Noakes, T. (2002). Electromyographic (EMG) normalization method for cycle fatigue protocols. *Medicine and Science in Sports and Exercise, 34*(5), 857-861.

Jeukendrup, A., Craig, N., & Hawley, J. (2000). The Bioenergetics of world class cycling. *Journal of Science and Medicine in Sport, 3*(4), 414-433.

Jeukendrup, A. E., & Martin, J. (2001). Improving cycling performance: how should we spend our time and money. *Sports Medicine, 31*(7), 559-569.

Jones, A., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine, 29*(6), 373-386.

Jones, D., & Polland, J. (2001). Strength training in young adults. In N. Maffulli, K. Chan, R. Macdonald, R. Malina & A. Parker (Eds.), *Sports Medicine for Specific Ages and Abilities*: Churchill Livingstone.

Kraemer, W., Fleck, S., & Evans, W. (1996). Strength and power training: physiological mechanisms of adaptation. *Exercise and Sports Science Reviews, 24*, 363-397.

Kyle, C. (1996). Selecting cycling equipment. In E. Burke (Ed.), *High-Tech Cycling*. Champaign, IL: Human Kinetics.

Lafortune, M., & McLean, B. (1989a). *Biomechanical Investigation of pedalling techniques of elite and recreational cyclists: coaches report*: Australian Sports Commission.

Lafortune, M., & McLean, B. (1989b). *Biomechanical investigation of pedalling techniques of elite and recreational cyclists: technical report*: Australian Sports Commission.

Laplaud, D., Hug, F., & Grelot, L. (2005). Reproducibility of eight lower limb muscles activity level in the course of an incremental pedaling exercise. *Journal of Electromyography and Kinesiology, 16*(2), 158-166.

Lepers, R., Hausswirth, C., Maffiuletti, N., Brisswalter, J., & Van Hoecke, J. (2000). Evidence of neuromuscular fatigue after prolonged cycling exercise. *Medicine and Science in Sports and Exercise, 32*(11), 1880-1886.

Lepers, R., Maffiuletti, N., Rochette, L., Brugniaux, J., & Millet, G. (2002). Neuromuscular fatigue during a long duration cycling exercise. *Journal of Applied Physiology, 92*, 1487-1493.

Li, L. (2004). Neuromuscular control and coordination during cycling. *Research Quarterly for Exercise and Sport, 75*(1), 16-22.

Lucia, A., Hoyos, J., Perez, M., & Chicharro, J. (2000). Heart rate and performance parameters in elite cyclists: a longitudinal study. *Medicine and Science in Sports and Exercise, 32*(10), 1777-1782.

Luttrell, M. D., & Potteiger, J. A. (2003). Effects of short-term training using powercranks on cardiovascular fitness and cycling efficiency. *Journal of Strength and Conditioning Research, 17*(4), 785-791.

Marsh, A. P., Martin, P. E., & Foley, K. O. (2000). Effect of cadence, cycling experience, and aerobic power on delta efficiency during cycling. *Medicine and Science in Sports and Exercise, 32*(9), 1630-1634.

Mileva, K., & Turner, D. (2003). Neuromuscular and biomechanical coupling in human cycling. *Experimental Brain Research, 152*, 393-403.

Minetti, A., Pinkerton, J., & Zamparo, P. (2001). From bipedalism to bicyclism: evolution in energetics and biomechanics of historic bicycles. *Proceedings Royal Society of London 268*, 1351-1360.

Mirka, G. (1991). The quantification of EMG normalization error. *Ergonomics, 34*(3), 343-352.

Moseley, L., & Jeukendrup, A. (2001). The reliability of cycling efficiency. *Medicine and Science in Sports and Exercise, 33*(4), 621-627.

Mujika, I., & Padilla, S. (2001). Physiological and performance characteristics of male professional road cyclists. *Sports Medicine, 31*(7), 479-487.

Narici, M., Hoppeler, H., Kayser, B., Landoni, L., Claassen, H., Gavardi, C., et al. (1996). Human quadriceps cross-sectional area, torque and neural activation during 6 months strength training. *Acta Physiologica Scandinavica, 157*, 175-186.

Nuckles, J., Bills, B., Wagner, D., & Bressel, E. (2007). *PowerCranks versus normal cranks: an EMG comparison*. Paper presented at the Southwest regional meeting of the American College of Sports Medicine.

O'Toole, M., & Douglas, P. (1995). Applied physiology of triatholon. *Sports Medicine, 19*(4), 251-267.

Padilla, S., Mujika, I., Angulo, F., & Goirena, J. (2000). Scientific approach to the 1-h cycling world record: a case study. *Journal of Applied Physiology, 89*, 1522-1527.

Paton, C., & Hopkins, W. (2001). Tests of cycling performance. *Sports Medicine, 31*(7), 489-496.

Pruitt, A. (1988). The cyclist's knee: anatomical and biomechanical considerations. In E. Burke & M. Newsom (Eds.), *Medical and Scientific Aspects of Cycling*. Colorado Springs, CO: Human Kinetics.

Ratel, S., Duche, P., Hautier, C., Williams, C., & Bedu, M. (2004). Physiological responses during cycling with noncircular "harmonic" and circular chainrings. *European Journal of Applied Physiology, 91*(1), 100-104.

Rhea, M. (2004). Determining the magnitude of treatment effects in strength and training research through the use of the effect size. *Journal of Strength and Conditioning Research, 18*(4), 918-920.

Ryan, M., & Gregor, R. (1992). EMG profiles of lower extremity muscles during cycling at constant workload and cadence. *Journal of Electromyography and Kinesiology, 2*(2), 69-80.

Sale, D. (1988). Neural adaptation to resistance training. *Medicine and Science in Sports and Exercise, 20*(5), S135-145.

Sanderson, D., & Cavanagh, P. (1990). Use of augmented feedback for the modification of the pedaling mechanics of cyclists. *Canadian Journal of Sports Science, 15*(1), 38-42.

Santalla, A., Manzano, J., Perez, M., & Lucia, A. (2002). A new pedaling design: the Rotor - effects on cycling performance. *Medicine and Science in Sports and Exercise, 34*(11), 1854-1858.

Sargeant, A., & Davies, C. (1977). Forces applied to cranks of a bicycle ergometer during one and two leg cycling. *Journal of Applied Physiology, 42*, 514-518.

Sarre, G., Lepers, R., Maffiuletti, N., Millet, G., & Martin, A. (2003). Influence of cycling cadence on neuromuscular activity of the knee extensors in humans. *European Journal of Applied Physiology, 88*(4 - 5), 476-479.

Schmidt, R., & Wrisberg, C. (2000). *Motor learning and performance*. Champaign, IL: Human Kinetics.

Sidewells, C. (2003). *Complete Bike Book*. London: Dorling Kindersley.

Smak, W., Neptune, R., & Hull, M. (1999). The influence of pedaling rate on bilateral asymmetry in cycling. *Journal of Biomechanics, 32*, 899-906.

Spriet, L., & Peters, S. (1998). Influence of diet on the metabolic responses to exercise. *Proceedings of the Nutrition Society, 57*, 25-33.

Takaishi, T., Yamamoto, T., Takaishi, O., Ono, T., ITO, T., & Moritani, T. (1998). Neuromuscular, metabolic, and kinetic adaptations for skilled pedaling performance in cyclists. *Medicine and Science in Sports and Exercise, 30*(3), 442-449.

Ting, L., Kautz, S., Brown, D., & Zajac, F. (2000). Contralateral movement and extensor force generation alter flexion phase muscle coordination in pedaling. *Journal of Neurophysiology, 83*, 3351-3365.

Ting, L., Raasch, C., Brown, D., Kautz, S., & Zajac, F. (1998). Sensorimotor state of the contralateral leg affects ipsilateral muscle coordination of pedaling. *Journal of Neurophysiology, 80*(3), 1341-1351.

Tucker, R., Raunch, L., Harley, Y., & Noakes, T. (2004). Impaired exercise performance in the heat associated with an anticipatory reduction in skeletal muscle recruitment. *European Journal of Physiology, 448*, 422-430.

Visich, P. (1988). Physiological changes riding a bicycle ergometer with and without toe stirrups. In E. Burke & M. Newsom (Eds.), *Medical and Scientific Aspects of Cycling* Colorado Springs, CO: Human Kinetics.

Wilson, D. (1988). Human powered vehicles: evolution and future. In E. Burke & M. Newsom (Eds.), *Medical and Scientific Aspects of Cycling*. Champaign: Human Kinetics.

Zamparo, P., Minetti, A. E., & di Prampero, P. E. (2002). Mechanical efficiency of cycling with a new developed pedal-crank. *Journal of Biomechanics, 35*, 1387-1398.

CHAPTER 9: APPENDIX

9.1 Appendix A: Statistical Data

Table 7. Two-way ANOVA ($p < 0.05$) p-values for group x time comparison, pre- to post-training.

	p value		
Variable	Group	Time	Group by Time
$\dot{V}O_2$ ($ml^{-1} \cdot kg^{-1} \cdot min$)	0.512	0.942	0.386
PPO (W)	0.868	0.912	0.991
$\dot{V}T_1$ ($\%L \cdot min^{max-1}$)	0.868	0.45	0.791
$\dot{V}T_2$ ($\%L \cdot min^{max-1}$)	0.153	0.823	0.665
$\dot{V}T_1$ VO2 ($L \cdot min^{-1}$)	0.933	0.43	0.773
$\dot{V}T_2$ VO2 ($L \cdot min^{-1}$)	0.413	0.81	0.392
$\dot{V}T_1$ PO (%PPO)	0.769	0.497	0.409
$\dot{V}T_2$ PO (%PPO)	0.084	0.474	0.613
$\dot{V}T_1$ PO (W)	0.883	0.481	0.544
$\dot{V}T_2$ PO (Watts)	0.274	0.591	0.749
Economy ($W \cdot L^{-1}$)	0.411	0.375	0.002†
Efficiency (%)	0.66	0.265	0.005†
iEMG -VL (%MVIC)	0.87	0.429	0.988
iEMG - BF (%MVIC)	0.823	0.927	0.426
iEMG - GAS (%MVIC)	0.506	0.278	0.605

Note. † denotes significance. $\dot{V}O_{2MAX}$ = maximal oxygen consumption, PPO = peak power output, $\dot{V}T_1$ = 1st ventilatory threshold, $\dot{V}T_2$ = 2nd ventilatory threshold, $\dot{V}O_2$ = oxygen consumption, PO = power output, PC = PowerCranks™ Test, iEMG = Integrated Electromyography, VL = Vastus Lateralis, BF = Biceps Femoris, GAS = Gastrocnemius, MVIC = maximum voluntary isometric contraction.

Table 8. One-way ANOVA ($p < 0.05$) p-values for pre- to post-training comparison for normal cranks and PowerCranks™ groups.

	p Value	
Variable	Normal Cranks	PowerCranks™
$\dot{V}O_2$ ($ml^{-1} \cdot kg^{-1} \cdot min$)	0.415	0.632
PPO (Watts)	0.935	0.941
$\dot{V}T_1$ ($\%L \cdot min^{max-1}$)	0.517	0.709
$\dot{V}T_2$ ($\%L \cdot min^{max-1}$)	0.905	0.505
$\dot{V}T_1$ O_2 ($L \cdot min^{-1}$)	0.772	0.301
$\dot{V}T_2$ O_2 ($L \cdot min^{-1}$)	0.678	0.423
$\dot{V}T_1$ PO (%PPO)	0.4	0.877
$\dot{V}T_2$ PO (%PPO)	0.909	0.139
$\dot{V}T_1$ PO (Watts)	0.437	0.929
$\dot{V}T_2$ PO (Watts)	0.886	0.52
Economy ($W \cdot L^{-1}$)	0.009*	0.083
Efficiency (%)	0.027*	0.093
Economy (PCT) - ($W \cdot L^{-1}$)	N/A	0.173
Efficiency (PCT) – (%)	N/A	0.281
Cadence ($revs \cdot min^{-1}$)	0.352	0.305
Cadence (PCT) – ($revs \cdot min^{-1}$)	N/A	0.005*
iEMG – VL (%MVIC)	0.536	0.61
iEMG – BF (%MVIC)	0.58	0.571
iEMG – GAS (%MVIC)	0.718	0.206

iEMG – VL (%MVIC) - PCT	N/A	0.619
iEMG – BF (%MVIC) - PCT	N/A	0.725
iEMG – GAS (%MVIC) - PCT	N/A	0.795
Girth – Upper (cm)	0.836	0.77
Girth – Lower (cm)	0.678	0.916
Heart Rate	0.885	0.989
Heart Rate (PCT)	N/A	0.866
RPE	0.865	0.055
Sessional RPE	0.512	0.227

Note. * denotes significance. $\dot{V}O_{2MAX}$ = maximal oxygen consumption, PPO = peak power output, $\dot{V}T_1$ = 1st ventilatory threshold, $\dot{V}T_2$ = 2nd ventilatory threshold, O_2 = oxygen consumption, PO = power output, PCT = PowerCranks™ Test, revs·min^{-1} = revolutions per minute, iEMG = Integrated Electromyography, VL = Vastus Lateralis, BF = Biceps Femoris, GAS = Gastrocnemius, MVIC = maximum voluntary isometric contraction, Upper = upper leg circumference, Lower = lower leg circumference, RPE = rating of perceived exertion.

9.2 Appendix B: Information Letter and Informed Consent Documents

Information Letter to Participants

For the study

Does training with PowerCranks™ modify muscle activation patterns, economy of motion, cycling efficiency and cycling performance in trained cyclists?

Thank you for expressing interest in this study. The following information is designed to inform you of the purpose and procedures involved in the study.

Purpose of the Study
This study aims to determine if a newly developed pedal crank has an effect on cycling performance.

Why were you selected?
You have been selected because you indicated that you have, to the best of your knowledge:

- At least 3 years riding experience,
- Not completed any previous training on Powercranks™,
- Usually ride 200+ km per week and can do so for the duration of the study (7 weeks).

What will be asked of you?
The study requires that you participate for seven weeks. During these seven weeks you will complete five training weeks, and two testing weeks as depicted in the timeline figure below. All testing sessions will occur indoors at ECU Joondalup, on a stationary cycle ergometer to which you can fit your own pedals. All training sessions will occur on your own bicycle to which the PowerCranks™ will be fitted.

Timeline of events

Week 1: Pre Training		Weeks 2 - 6	Week 7: Post Training
Familiarisation & Testing: VO2max Efficiency 2 x 2hr Sessions	PowerCranks Familiarisation. 2 x 1hr Sessions	Regular training on own bike (fitted with PowerCranks or your normal cranks)	Testing: VO2max Efficiency Time-trial 2 x 2hr Sessions

During each testing week we will measure your endurance capacity (VO_2max) on one day, and your cycling efficiency and economy two to four days later. Those allocated to the PowerCranks™ group will then partake in two additional familarisation sessions to become accustomed to the cranks.

Based on the information from your first testing week, you will be allocated to one of two groups; these being a PowerCranks™ group or a control group.

For the training weeks, the appropriate cranks will be fitted to your bike (i.e. PowerCranks for the PC group or your normal cranks for the control group) and you will be required to train as you would usually. You will be given a training diary for this five-week period that you will be asked to fill in with as much detail as possible.

Will you experience any discomfort or inconvenience? What are the Potential risks?

1. The Graded Exercise Tests (VO_2max) are designed to elicit maximal effort and are therefore fatiguing and may cause some discomfort. During the test you will wear a mouthpiece, similar to a snorkel, so that we can analyze your expired gases. Some participants have found breathing through the mouthpiece is initially awkward; however this feeling disappeared after a few minutes.
2. Hair will be shaved in certain places of the left leg to affix 2 by 2 cm EMG (Electromyography) electrodes.
3. In each VO_2max test several fingertip blood samples will be collected from you (the total amount of blood taken during the study will not exceed 15 ml). This involves the use of a small needle to pierce the skin. Usually after fingertip blood sampling fingertips are sensitive for a day or two. Additionally, these samples will only be used for obtaining blood lactate measurements and samples will be immediately disposed of once this has been carried out.
4. When the PowerCranks™ are attached to the bicycle it is initially difficult to cycle and to clip in and out of the pedals. You will however be given familarisation sessions on the PowerCranks™ in a safe controlled environment to give you practice cycling with the cranks.
5. Participants allocated to the PowerCranks™ group may experience some muscle soreness in the first few weeks - this is perfectly normal. However, we ask you to tell us if you experience any problems resulting from your participation.

What are the benefits to you?

You will receive information pertaining to your maximal endurance capacity (VO_2max), cycling efficiency, cycling economy and other physiological values. You will also gain any benefits from the PowerCranks™ training and also receive a discount on the PowerCranks™ if you wish to purchase them after the study.

Confidentiality of information
All information provided to the investigator will be used in a strictly professional and confidential manner. During the course of the study information will be stored either, in a locked drawer or a password-protected computer. Only people relevant to the study shall be able to view any data pertaining to your results and even then every attempt will be made to ensure the data is displayed in such a way as to make it untraceable to you.

After the study has finished it is required that all data is kept for a minimum of 5 years, during this time all information will be stored on a password protected computer and all original materials will be destroyed.

Your information will be collated along with others in the study and conclusions drawn on the groups as a whole, no specific persons in the study will be individually scrutinized.

Results of the research study

Results of this study will be published in a variety of ways. First, they will comprise the investigators Masters Thesis. Second, they will be published in a journal, and third, they may be presented at a conference or research group in written or verbal form. Again this information will be group based and individuals will not be identifiable.
If you wish to know any of your individual results from the testing sessions please feel free to ask the investigator at an appropriate time.

Withdrawing consent to participate
It is important for you to know that you are participating in a voluntary nature in all procedures and are free to withdraw your consent to further involvement in the research project at any time. You need not give any explanation or justification as to why you can no longer participate. If this should occur any information or material pertaining to your involvement will be withdrawn.

Additional
This research project is being undertaken as part of the requirements of a Masters Degree at Edith Cowan University and has been approved by the ECU Human Research Ethics Committee.

This project will use equipment supplied by PowerCranks, LLC.

If you would still like to be a participant in this study, and you understand the commitment, risks and fit the criteria, then please respond to the primary investigator (Jack Burns) to set up a familiarisation meeting. Please also read the informed consent but do not sign it until you come into the laboratory for your familiarization meeting.

If you have any questions or require any further information about the research project, please contact:

Jack Burns (Masters Candidate)
School of Exercise, Biomedical and Sports Science
Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
Mobile: [redacted]
Email: jack.burns@ecu.edu.au

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

Informed Consent Document

For the study

Does training with PowerCranks™ modify muscle activation patterns, economy of motion, cycling efficiency and cycling performance in trained cyclists?

This is to certify that I _____ hereby agree to participate as a volunteer in a scientific investigation performed at Edith Cowan University.

The investigation and my part in the investigation have been defined and fully explained to me and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to ask any questions and that they will be answered to my satisfaction.
- I understand that as part of the testing I will be required to carry out maximal intensity exercise and have blood, electromyography (measure of muscle activity), gas analysis, ultrasonography, muscle girth, RPE and heart rate readings taken. I understand that I will be required to keep a training history and ride as per my regular training schedule.
- I also understand that the PowerCranks™ will be fitted to my bicycle and that riding on the PowerCranks™ presents an initial risk of injury and muscle soreness until I become accustom to the technique required.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time.
- I understand that my data and answers to my questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical condition that would increase the risk to me participating in this investigation.
- I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant _____ Date _____

I, the undersigned, was present when the study was explained to the subject in detail and to the best of my knowledge and belief it was understood.

Investigator _____ Date _____

Yours Sincerely,
Jack Burns (Masters Candidate)
School of Exercise, Biomedical and Sports Science
Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
Mobile: [redacted]
Email: jack.burns@ecu.edu.au

9.3 Appendix C: Subject Advertisement

The Exercise and Sport Science Research Group

At

Edith Cowan University, Joondalup

Is seeking

Cyclists or triathletes (18 to 45 years old) to participate in a five week training study examining the effects of training with PowerCranks™ on cycling performance.

Eligibility for the study requires that you:

- male
- have no medical illnesses
- regularly ride ≥200 km per week

Full study participation entitles you to buy a set of PowerCranks™ at a heavily discounted price.

To inquire about participating contact:

Jack Burns, [redacted], jack.burns@ecu.edu.au

Cycling PowerCrank Study. Exercise Sport Science Research Group. Edith Cowan University, Joondalup. Contact: Jack Burns at jack.burns@ecu.edu.au on [redacted]

Cycling PowerCrank Study. Exercise Sport Science Research Group. Edith Cowan University, Joondalup. Contact: Jack Burns at jack.burns@ecu.edu.au on [redacted]

Cycling PowerCrank Study. Exercise Sport Science Research Group. Edith Cowan University, Joondalup. Contact: Jack Burns at jack.burns@ecu.edu.au on [redacted]

Cycling PowerCrank Study. Exercise Sport Science Research Group. Edith Cowan University, Joondalup. Contact: Jack Burns at jack.burns@ecu.edu.au on [redacted]