The Effects of Traditional vs. Cycle based Strength Training on Power Production Capabilities and Performance of Sprint Track Cyclists

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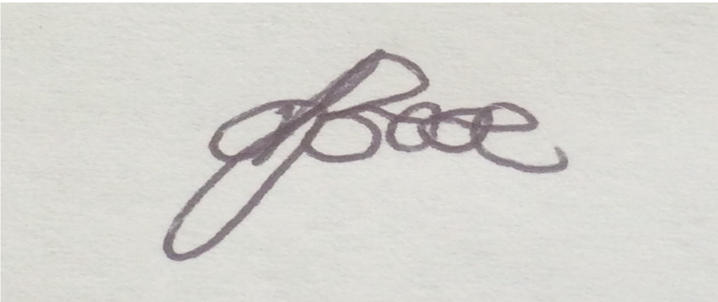
Attestation of Authorship.

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where acknowledgment is made in the acknowledgements.



James Brentwood Vercoe
9th December 2016

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Abstract:

The sport of track cycling is an Olympic disciplined event, commonly classified as a sprint sport due to the high levels of maximal or repeated maximal sprints required during events ranging from 250m to 30km in length. A major determinant of sprint cycling performance is a rider's ability to produce high levels of sustained power, regardless of event distance. As a result practitioners must ensure that mechanical and physiological components contributing to power are improved. This thesis sought to gain insight into the relationship between muscular strength and power capabilities of well trained sprint cyclists. From the literature review, significant improvements in force generating capability and muscle architecture characteristics were found as a result of externally loaded resistance training. Research had also reported that sport specific resistance training could elicit greater adaptations within trained individuals. Only one study had attempted to analyse the effects of traditional resistance training and cycling specific resistance training on endurance based cyclists, with no reporting of sprint cyclists found. Study One of the thesis showed significant relationships between muscular force and maximal torque production at all tested pedalling velocities ($r = 0.890 - 0.925$), while muscular force and power production were found to not be significantly related. Study Two was conducted using well trained sprint cyclists and sought greater understanding on optimal training modalities. No substantial differences in the relationship of muscular force and maximal torque were found as a result of traditional gym based resistance training (Effect size (ES) = 0.06) or cycling specific isokinetic resistance training (ES = -0.12). Additionally no worthwhile changes in maximal cycling power were found as a result of either traditional (ES = 0.02) or isokinetic (ES = 0.09) training modalities. It is suggested that the use of traditional and cycling specific strength training should be carried out regardless of training level, in order to elicit muscular adaptations and maintain sprint cycling performance.

Chapter One: Introduction and Rationale.

Background.

Track cycling is regarded as a sprint based sport, with athletes required to perform maximal or repeated maximal sprints (Cormie, McGuigan, & Newton, 2011a; 2011b; Craig & Norton, 2001; Higbie, Cureton, Warren, & Prior, 1996; Putman, Xu, Gillies, MacLean, & Bell, 2004). A Union Cycliste Internationale (UCI) regulated Track Cycling World Championships consists of a number of events in which sprinting is a vital factor of performance (Martin, Davidson, & Pardyjak, 2007). Both male and female athletes participate in four maximal sprint events (Time Trial, Sprints, Keirin and Team Sprint), a repeated sprint event (Points race) and an endurance event commonly decided by a sprint finish (Scratch Race) (Martin et al., 2007). As a result of the requirement for sprint ability during track cycling races, it is suggested that the ability to perform maximal sprints through the production of large amounts of sustained power is a vital component contributing to track cycling performance (Dorel et al., 2005; Emanuele & Denoth, 2011; Gardner, Martin, Barras, Jenkins, & Hahn, 2005). Despite sprint ability being identified as a major determinant of track cycling performance, there remains a lack of information and in particular practical recommendations in regards to both sprint cycling performance and optimal sprint cycling training prescription.

Sprint cycling performance is determined by an individuals ability to produce large amounts of sustained power (Dorel et al., 2005; Gardner, Martin, Barras, & Jenkins, 2007; Gardner et al., 2005; Martin et al., 2007). Tactical and psychological factors also contribute to overall sprint cycling performance (Schumacher, Mueller, & Keul, 2001). The ability to produce power in a cyclic movement such as in cycling can be defined using the power velocity relationship (Emanuele & Denoth, 2011; Martin et al., 2007), with power being the product of torque applied to the pedal surface in relation to the angular velocity of the rotating crank arm (McCartney, Obminski, & Heigenhauser, 1985; Samozino, Horvais, & Hintzy, 2007). Studies have shown that the potential for power production during cycling increases with pedalling rate, with optimal muscle shortening velocity and ultimate force production capability occurring between 120-140 rpm (Emanuele & Denoth, 2011; Gardner et al., 2005; Martin et al., 2007). The optimisation of both torque and angular velocity is commonly referred to as the optimal pedalling rate of power (Dorel et al., 2005; Emanuele & Denoth, 2011; Martin et al., 2007; Samozino et al., 2007). To improve power production capabilities during maximal sprint cycling researchers have suggested that one or both aspects of the force velocity relationship must be improved (Martin et al., 2007; Martin, Wagner, & Coyle, 1997; Rannama et al., 2013; Stone et al., 2004). Increases in muscle fibre recruitment rates to improve force production capability is regarded as one of the most beneficial training approaches when improvement in power production is required (Izquierdo et al., 2004; Jackson, Hickey, & Reiser, 2007; Martin et al., 2007). Currently there is research regarding the use of strength resistance training in improving force development and overall power generating capabilities of sprint orientated athletes (Baker & Newton, 2006; Cormie, McGuigan, & Newton, 2011b; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997). However limited research is available regarding resistance training approaches when used on road or track orientated cyclists, and more specifically sprint disciplined track cyclists.

Resistance training has been shown to improve force production capabilities in sporting events that require rapid acceleration or maximal power production, including short distance sprint running events, athletic throwing events and team sports (Baker & Newton, 2006; Campos et al., 2002; Cormie, McGuigan, & Newton, 2011). Increases in force production as a result of resistance training has shown to be caused by increased hypertrophy and neural activation of the recruited muscle fibres (Baker & Newton, 2006; Folland, Buckthorpe, & Hannah, 2013; Ronnestad, Hansen, & Raastad, 2009; Saez de Villarreal, Requena, Izquierdo, & Gonzalez-Badillo, 2013). Attempts to understand the effect of strength training on cyclists has been examined through structured resistance training with endurance based cyclists (Jackson et al., 2007; Ronnestad et al., 2009). The prescription of high and low load resistance strength training has shown to cause improvement in the force generating capabilities of endurance cyclists (Jackson et al., 2007; Ronnestad et al., 2009), with improvement in endurance time trial cycling performance also found (Ronnestad et al., 2009). However it is unclear whether the improvement in endurance cycling performance found in the Ronnestad et al., (2009) study was the direct result of a strength training stimulus, as this training study also involved a form of cross country skiing which may have contributed to the improvement in muscular strength and cycling performance. Strength training prescription in non cyclists has also shown an improvement in maximal power production capability post intervention (Beck et al. 2007; Chromiak et al. 2004). Research suggests improvements in force production capability can also occur in untrained cyclists using lighter loads (velocity based training) (Jackson et al., 2007).

There is currently little research regarding the relationship between muscular strength and performance in sprint disciplined track cyclists. In addition, no specific research exists on the optimal training approach to improve sprint cycling performance. The use of cycling specific training such as isokinetic cycle training or high load resistance cycle training, is thought to improve force production capabilities and be more transferable to cycling performance than that of force developed through traditional gym based strength training (Koninckx, Van Leemputte, & Hespel, 2010).

Purpose Statement.

The primary purpose of this thesis was to investigate the relationship that muscular force and velocity has with a trained sprint cyclist's ability to produce power during maximal sprint bouts. The second purpose was to investigate the effects that off bike and on bike strength training had on power production capabilities in trained sprint cyclists.

An assessment of the relationship muscular strength had with power production capabilities during maximal sprint cycling was carried out, including analysis of maximal isometric strength and lower limb velocity. In addition, the effect of a gym based strength development and a cycling based strength development training approach over a five week period was investigated in well trained cyclists, including changes to force and velocity characteristics as a result of the different modes of training. Practical recommendations have also been provided based on the findings of each study and recommendations for future study outlined.

Study Aims.

The specific aims of this research were:

1. To review current literature regarding the effects of muscular strength on power production and overall performance of track cyclists, as well as review current literature on different strength development approaches for track cycling athletes.
2. To examine the relationship between muscular force generating capacity and maximal power production capabilities of well trained track cyclists.
3. To investigate the effects of "on bike" vs. "off bike" strength development approaches on muscular force, power production capability and overall performance of well trained sprint cyclists.
4. To provide practitioners with a greater understanding of the optimal approach to increasing power production capability and overall performance of track cyclists, through improved strength development.

Structure of Thesis..

This thesis consists of five chapters, which includes both original research and a literature review. References are included as an overall reference list for all chapters at the end of this thesis. The overall chapter structure of this thesis is outlined by a flow chart in Figure 1.1. The second chapter contains a review of the literature relating to different strength development approaches currently used to improve power production capabilities in sprint based athletes, with specific discussion in regards to track cyclists where applicable. Firstly the physiological and mechanical principles that relate to power production in cycling were reviewed. The influence of varying training modalities on improved power production were also reviewed and practical guidelines surrounding appropriate sprint specific training were suggested following the review. Chapter three consists of a study where the effects of force generating capability are assessed in regards to the ability to produce maximal power during maximal cycling specific performance assessments. The fourth chapter consists of a cross over training study looking at the effects that a cycling specific vs. non cycling specific strength development approach has on power production capabilities and performance indicators in trained sprint cyclists. The final chapter includes an overall discussion of the findings as well as practical recommendations and future considerations.

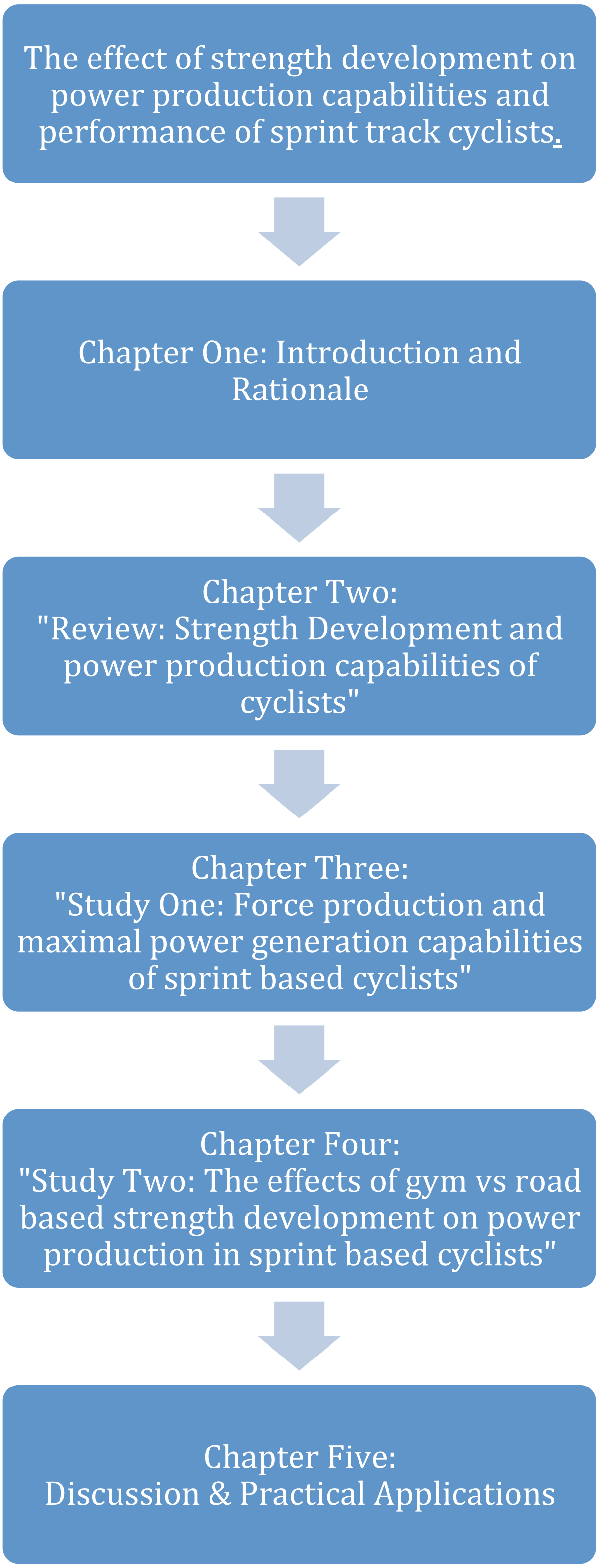

Figure 1.1. Outline of Thesis Structure

Chapter Two: Literature Review

Force-Velocity relationship.

The capacity of lower limb musculature to generate maximal or sustained power during cyclic movements using the force velocity relationship has been well documented (Dorel et al., 2005; Samozino et al., 2007; Stone et al., 2004). Researchers have reported maximal power generation during cycling is the result of a polynomial relationship between torque applied to the pedal surface by the working musculature and velocity of the rotating crank arm (Dorel et al., 2005; Emanuele & Denoth, 2011; Martin et al., 2007; McCartney et al., 1985). During maximal bouts of cycling, maximal power (Pmax) has been suggested to be achieved at an optimal pedaling rate of 110-140 revolutions per minute (rpm) (Martin et al., 2007; Samozino et al., 2007). The concept of optimal pedaling rates of power is well recognized amongst cycling specific research with Pmax reported to occur between 110-120rpm (Table 2.1) (Arsac, Belli, & Lacour, 1996; Hautier, Linossier, Belli, Lacour, & Arsac, 1996; Martin et al., 2007). However a number of studies have noted that Pmax can be achieved at a higher cadence of 120-130rpm (Arsac et al., 1996; Hautier et al., 1996; Martin et al., 2007). Variances found in Pmax cadence ranges could be the result of inertial loading placed on the ergometer prior to completing the maximal sprint, with greater external load potentially restricting the maximal crank arm velocity able to be achieved (Falgairette, Billaut, Glacomoni, Ramdani, & Boyadjian, 2004).

Irrespective of the given cadence range all researchers conclude that Pmax can only be achieved when both components of the force-velocity relationship are at optimal levels (Emanuele & Denoth, 2011; Martin et al., 2007; Samozino et al., 2007). Analysis of both maximal and sub maximal cycling has shown that power production increases to where both the force applied to the pedal surface and crank velocity are optimised (Dorel et al., 2005; Gardner et al., 2007; Samozino et al., 2007). Once force application and crank arm velocity have reached a point of optimisation, power decreases as a result of the increasing rotational velocity of the crank arm, causing a compromised ability to apply maximal force to the pedal surface (Dorel et al., 2005; Falgairette et al, 2004; Samozino et al., 2007). Samozino et al (2007) reported that during maximal cycling there was the potential for power production to increase with pedaling rate and reach a maximal rate around 200rpm. As a result of the Samozino et al (2007) intervention, it was shown that pedaling rate corresponded directly to the muscle-shortening velocity belonging to the ascending limb, while activation dynamics of the lower limb musculature had a detrimental effect on power production with increasing pedaling rates. Together these opposing trends concluded that maximal power production during cycling can only occur at an optimal pedaling rate of 110-130rpm (refer to Table 2.1) (Samozino et al., 2007).

In a review of sprint cycling performance, Martin et al (2007) showed a similar optimal pedaling range to that of Samozino et al (2007). Further analysis suggested that pedal rate in conjunction with crank length determines pedal velocity and thereby sets the shortening velocity for uniarticular muscles that span the hip, knee and ankle joints (Martin et al., 2007). Like other studies that have investigated power and optimal pedaling rate phenomenon in cycling, Martin et al (2007) suggested that power output would initially increase with increasing shortening velocity, reach a maximum, then decrease as further increases in velocity occur. However unlike other studies, Martin et al (2007) provided further information into the potential relationship between muscle physiology and the force velocity relationship. The researchers found that during a maximal cycle sprint crank arm velocity sets the time frame in which the working musculature must become excited, produce force while shortening and relax before lengthening (Martin et al., 2007). This time frame is reported to be 250 milliseconds at 120rpm, further supporting the idea of an optimal pedaling rate, with higher pedaling velocities shown to reduce muscle force capability as a result of excitation relaxation kinetics (Martin et al., 2007). The concept of muscle contractile rates being influenced by pedaling rate has previously been discussed within cycling research (Samozino et al., 2007), while studies on stride cadences in sprint based runners have suggested a link between contractile velocities and force application capabilities (Delecluse, 1997).

The current literature makes it evident that the force-velocity relationship is the framework that determines maximal power production in both endurance and sprint based cyclists (Dorel et al., 2005; Gardner et al., 2007; Samozino et al., 2007). Therefore it can be suggested that an improvement in one or both components of the force-velocity relationship would result in an improvement in power production at varying pedaling rates. With an increase in force production correlating with a likely shift in the polynomial relationship towards maximal power being achieved at lower pedaling rates, while an improvement in crank velocity capability would result in maximal power being achieved at higher pedaling rates (Dorel et al., 2005). As previously mentioned true peak power is achieved within an optimal pedaling rate (Emanuele & Denoth, 2011; Martin et al., 2007; Samozino et al., 2007) and therefore improvement in both force and velocity capabilities are warranted. Further understanding is required around which training effects if any result in improved force or velocity generating capability. Additionally further information around correct inertial loading to elicit true optimal pedaling rates would also be advantageous for future cycling based literature.

Table 2.1 Torque and Velocity and Power Relationships within Maximal Sprint Cycling.

Study (Year)	Type of Subjects	Testing Method	Torque & Velocity	Power
Arsac et al (1996)	15 trained male subjects.	Six randomised 8s sprints at 0.25, 0.35, 0.45, 0.55, 0.65 and 0.75 $N.kg^{-1}$	f_{opt} (rpm): 125 ± 9	Pmax (W): 868 ± 132 *Pmax (W) values collected at 0.25 and 0.65 $N.kg^{-1}$ were sig different (p<0.05)
Dorel et al. (2007)	12 elite trained male cyclists.	Anthropometric Measurements Torque velocity Test: 3x5s max sprints (seated), resistance (0.287, 0.573, 0.859 $N.m.kg^{-1)}$ Flying 200m Sprint: 250m outdoor wooden track, max velocity calculated by $f_{200} = (V_{200}.60)/D_{R.}$	T_0 (N□M): 236 ± 19* T_{opt} (N□M): 118 ± 10* f_0 (rpm): 260 ± 9 f_{opt} (rpm): 130 ± 5 * T_0 & T_{opt} sig relationship with lean leg volume (r=0.77, p=<0.01 and r=0.69, p=<0.01)	Pmax (W): 1600 ± 116* Pmax ($W.kg^{-1}$): 19.3 ± 1.3 *Pmax sig correlated with T_0 & T_{opt} (r=0.92, p=<0.001 and r=0.91, p=<0.001)
Gardner et al (2005)	Three elite male track sprint cyclists.	Anthropometric Measurements. 36 race profiles using SRM calibrated power meter.	INT f_{opt} (rpm): 127 ± 10 DOM f_{opt} (rpm): 133 ± 8* * sig difference between INT f_{opt} & DOM $f_{(opt)}$ (p= <0.05)	INT Pmax (W): 1898 ± 245 DOM Pmax (W): 1968 ± 239 INT Pmax ($W.kg^{-1}$): 21.7 ± 1.4 DOM Pmax ($W.kg^{-1}$): 22.6 ± 1.6
Samozino et al (2007)	11 well trained male cyclists.	Four randomised 8s sprints (seated) at 0.5, 0.75, 0.75 and 0.90 $N□kg^{-1.}$	f_{opt} (rpm): 120 ± 9	Pmax ($W.kg^{-1}$): 9.55 ± 0.99

McCartney et al (1985)	Seven female university students, untrained in cycling.	Maximal Isometric Contraction (crank locked at 90 degrees). 10s sprint (seated) (functionally unloaded).	Isometric peak T_0 (N□M): 153-223 f_0 (rpm): 181-192 Mean T expressed at each f: $y=189.6 \times e^{-0.0834}x$	Pmax (W): 767-1187* *Pmax achieved between 120-160rpm.
Stone et al (2004)	30 Male Cyclists (5 Olympic standard, 10 international BMX, 15 regional cyclists)	Anthropometric Measurements. Maximal Isometric Mid Thigh Pull Test (2-3 trials of 8sec). Vertical Jump Power Test. 18sec inertia corrected Wingate Sprint Test.	Isometric Peak Force: 3706 ± 719 Isometric Peak Force per kg of BW: 46 ± 6 Isometric Peak Rate of Force Development: 15162 ± 5531	Pmax (W): 1581 ± 294 Pmax (W/Kg): 19.6 ± 2.1

* significant relationship between one or more tested variables ($p<0.05$)

Key:
Maximum Power = Pmax
Optimal Pedalling Rate = f_{opt}
Maximal Pedalling Rate = f_0
Torque at Optimal Pedalling Rate = T_{opt}
Maximal Torque = T

Physiological contribution to power production in sprint cyclists.

Within a cycling context, contraction characteristics of recruited skeletal musculature have been shown to be influenced by the force and velocity of the muscle contraction caused by pedal surface torque and crank arm velocity (Arsac et al., 1996; Ewing, Wolfe, Rogers, Amundson, & Stull, 1990). Research has identified contractile and neural activation responses as key adaptations within recruited muscle fibres (Arsac et al., 1996; Ewing et al., 1990).

Analysis of contractile velocities and force capabilities have shown that when a stimulus is applied to the working musculature in a structured manner a physiological change occurs to one or both muscular components allowing for improvement in athletic performance (Campos et al., 2002; Cormie, McGuigan, & Newton, 2011a; 2011b; Folland et al., 2013). Increased muscular force production has been shown to cause significant improvement to athletic performance where muscular power demands are high (Koninckx, Van Leemputte, & Hespel, 2010; Martin et al., 2007; Stone et al., 2004). Longitudinal and cross sectional studies have been carried out to examine the effect of heavy resistance training on muscle architecture adaptations (Baker & Newton, 2006; Campos et al., 2002; Higbie et al., 1996). Findings have shown that when external resistance is applied to a contracting muscle, the required force to overcome the external load is solely dependent on the amount of active cross bridges within the contracting muscle (Campos et al., 2002; Cormie, McCaulley, Triplett-McBride, & Mcbride, 2007; Cormie, McGuigan, & Newton, 2011a; Jackson et al., 2007). Increases in contractile velocity have also shown to contribute to improved athletic performance, mainly in sports where high limb velocity is required (Cronin, McNair, & Marshall, 2013; Ewing et al., 1990). The ability to increase contractile velocity however has shown to be somewhat limited due to muscle fibre firing patterns and overlap of muscular properties within singular muscle fibres (Cormie, McGuigan, & Newton, 2011a; Ewing et al., 1990).

Cormie et al. (2007) highlighted that in order for optimal levels of active cross bridges to occur within the contracting muscle that the muscle shortening velocity must occur within a range that allows for maximal actin and myosin filament overlap. The interaction between actin and myosin filaments is dependent on the length of each sarcomere during muscular contraction, with high contractile velocities shown to cause interference between actin filaments along the sarcomere, resulting in a compromised cross bridge and inability to produce muscular force within the sarcomere (Cormie, McGuigan, & Newton, 2011a). When applied within a cycling context it can be suggested that if pedaling rate becomes too high then this would correlate highly with a high muscular contraction velocity (Dorel et al., 2005; Emanuele & Denoth, 2011), resulting in an inability to produce high levels of force. This theory of contractile rate velocities provides further insight as to why power production during maximal cycling decreases once crank arm velocity exceeds the known optimal pedaling rate.

In order to elicit changes to muscular mechanics or muscular properties a stimulus must be applied to the working musculature, with external loading through resistance training reported as one of the most common and applicable approaches for untrained and trained individuals (Higbie et al., 1996; Moss et al., 1997; Ronnestad et al., 2009). Resistance training has been shown to cause changes in sarcomere length, muscle fibre cross sectional area and muscle fibre firing patterns, all of which have been shown to improve force generating capability when tested in both lab and field settings (Cormie, McGuigan, & Newton, 2011a; 2011b; Craig & Norton, 2001; Higbie et al., 1996; Putman et al., 2004). Changes in muscle cross sectional area, as well as transition of muscle fibre types are highly correlated with improvement in muscular force generating capability (Baker & Newton, 2006; Campos et al., 2002; Cormie, McGuigan, & Newton, 2011a). Findings suggest that for sports in which power production is a major determinant of performance athletes should focus on increasing muscle fibre cross sectional area through structured resistance training (Cormie, McGuigan, & Newton, 2011b; Delecluse, 1997).

Traditional Strength Development for Athletes.

Research on the use of resistance training to elicit physiological adaptations and improve athletic performance has helped to establish approaches to developing strength in both sprint and endurance based athletes (Baker & Newton, 2006; Cormie, McGuigan, & Newton, 2011b; Parsons, 2010). Changes in muscle architecture, neural activation levels and contractile power have all been reported to be caused by periods of sustained structured resistance training in both trained and untrained individuals (Baker & Newton, 2006; Campos et al., 2002; Cormie, McGuigan, & Newton, 2011; Higbie et al., 1996). The use of traditional strength training and plyometric training modalities are the most common approaches reported to improve muscular power capabilities in both team and individual sport athletes (Cormie, McGuigan, & Newton, 2011b). Varying recommendations are found regarding optimal loading parameters and to date there is no conclusive evidence regarding the optimal resistance training modality for sprint based cycling performance (Adams, O'Shea, & Climstein, 1992; Baker & Newton, 2006; Campos et al., 2002; Fatouros et al., 2000; Saez de Villarreal et al., 2013).

Analysis of resistance training to improve athletic performance has shown that movement patterns of resistance exercises significantly influence the contractile patterns and overall force generating capability of the recruited muscle groups (Cronin et al., 2013; Delecluse, 1997; Saez de Villarreal et al., 2013). Stone et al (2002) noted that careful consideration should be taken by practitioners to ensure resistance exercises elicit similar joint range of motions and muscular activation patterns to that of the required sporting movement, when improvement in muscular power of dynamic, multi joint movements is required. Stone et al. (2002) also stated that joint angle specificity was key in improving dynamic athletic performance as the use of resistance training during a known range of motion improved the length-tension of the working musculature. Furthermore Stone et al (2002) established that free weight resistance exercise movements had a strong relationship with dynamic actions such as a countermovement vertical jump, suggesting that being able to mechanically mimic a dynamic action during resistance training may indeed improve the ability of the athlete to perform the given action. This concept is of importance in sports such as cycling, where the primary movement of pedaling is performance of a cyclic pattern, with joint angles across the hip, knee and ankle remaining constant, although it is acknowledged that slight variations in hip and ankle angles are observed when in a fatigued state (Bini & Carpes, 2014; Sarre, Lepers, & van Hoecke, 2005).

External loading ranges in order to elicit force production adaptations within the working musculature is varied for both traditional and ballistic based gym exercises (Cormie, McGuigan, & Newton, 2011). Traditional lower limb based exercises in which both the concentric and eccentric phases of the exercise are of a controlled nature and of similar duration have shown to cause change in muscle architecture and overall muscle function performance (Table 2.2) (Cormie, McGuigan, & Newton, 2011b; Higbie et al., 1996). Moss et al (1997) investigated the effect that dynamic strength training had on maximal strength, muscle cross sectional area and load velocity relationships and concluded that external loading can indeed cause changes in the architecture and force production characteristics of the worked muscle. External loading of 15%, 35% and 90% of bicep curl one repetition maximum (1RM) were used as loading guidelines during a nine week, three sessions per week training study. Results showed that all three load ranges resulted in an increase of measured maximal strength post intervention, with the largest improvement in muscular strength of 15.2% reported by the 90% 1RM group. Muscle fibre cross sectional area was also found to increase in the 90% and 35% groups, indicating that increased fibre size positively contributes to an increase in muscular strength. The 15% load group showed little or no change in muscle fibre cross sectional area but still improved in overall muscular strength post intervention indicating that changes to other muscle physiology characteristics such as firing frequency and fibre recruitment most likely pay a contributing role in improved muscular strength. The findings of this study suggest that irrespective of the prescribed loading parameters, if an individual was to carry out a form of structured resistance training then improvements in muscular strength would most likely occur.

Research on the use of strength training to improve athletic performance in sprint based athletes provides further understanding into the physiological adaptations caused by resistance training (Delecluse, 1997; Jackson et al., 2007). A study on sprint distance track runners reported that traditional strength exercises, where relatively high external load were used can cause significant changes to the muscular architecture and as a result a change in force production capabilities (Delecluse, 1997). The researchers reported that strength training aimed partly at selective hypertrophy of the working musculature, caused an increase in cross sectional area of the working fast twitch muscle fibres, as well as specific adaptation of the nervous system including increased motor unit recruitment and increased firing of motor neurons (Delecluse, 1997). These findings are consistent with those of other researchers who have found that maximal acceleration against near maximal external loads (90-100% 1RM) results in increased neural activation of fast twitch muscle fibres and overall increased force generating capability of the working musculature (Cormie et al., 2007; Moss et al., 1997).

Table 2.2 Effects of Strength Training on Trained and Untrained Individuals.

Study	Type of Subjects	Testing Method	Exercises Used.	Pre Training.	Post Training.
Campos et al (2002)	32 physically active (untrained) males	Maximal Strength Test (1RM) Muscle Biopsy Sample.	Leg Press, Barbell Back Squat, Leg Extension. LR group: 3-5reps x 4 sets IntR group: 9-11reps x 3 sets. HR group: 20-28reps x 2 sets.	Muscle Fibre cross sectional area (μm^2): IIA = 5615 ± 1042 (LR) 5238 ± 787 (Int) 5217 ± 1009 (HR) IIB = 4926 ± 942 (LR) 4556 ± 877 (Int) 4564 ± 1179 (HR)	Muscle Fibre cross sectional area (μm^2): IIA = 6903 ± 1442 (LR)* 6090 ± 1421 (Int)* 5633 ± 596 (HR) IIB = 6171 ± 1436 (LR)* 5798 ± 1899 (Int)* 5181 ± 714 (HR)
Jackson et al (2007)	23 trained club level cyclists (5 women, 18 men)	Maximal Strength Test (1RM) Lactate Profile Test (Cycle Ergometer)	Barbell Back Squat, Leg curls, Leg press, Single leg step ups. High Rep/Low load group (HR/LL): 20reps x 2 sets @ 50% 1RM Low Rep/High Load group (LR/HL): 4reps x 4 sets @ 85% 1RM	One repetition Maximum (kg): HR/LL = Squat: 100 ± 36.9 Leg Press: 162 ± 17.6 LR/HL = 116 ± 20.1 151 ± 27.3 Max Power (W): HR/LL = 330.6 ± 48.0 LR/HL = 305.6 ± 39.1	One repetition Maximum (kg): HR/LL = Squat: 122 ± 26.5 Leg Press: 164 ± 15.6 LR/HL = 151 ± 29.2 174 ± 5.5 Max Power (W): HR/LL = 338.9 ± 47.0 LR/HL = 305.6 ± 37.1

Moss et al (1997)	31 Well Trained Males	Maximal Strength Test (1RM) Maximal velocity & power test @ loads 15%, 25%, 35%, 50%, 70%, 90% of pre training 1RM Anatomical Cross Sectional Area of elbow flexor	Bicep Curl of one arm. Three groups: 90% of 1RM, 35% of 1RM, 15% of 1RM. 4 repetitions x 4-5 sets @ group 1RM percentage.	1RM lifted (kg): G90 = 18.8 ± 3.0 G35 = 20.0 ± 4.7 G15 = 19.0 ± 4.5 Muscle Cross Sectional Area (cm^2): G90 = 20.0 ± 2.5 G35 = 20.6 ± 3.9 G15 = 19.5 ± 3.7	1RM lifted (kg): G90 = 21.7 ± 3.3* G35 = 22.0 ± 5.1* G15 = 20.3 ± 5.0* Muscle Cross Sectional Area (cm^2): G90 = 20.4 ± 2.3 G35 = 21.2 ± 4.0* G15 = 20.0 ± 3.9
Ronnestad et al (2009)	23 Well Trained Cyclists.	Cross sectional area measurement of thigh muscle. Maximal Strength test (1RM) 30 second Wingate sprint test.	Back Squat Single Legged Leg Press One legged hip flexion Ankle Plantar Flexion. 10-4 reps over 6 weeks.	Peak Power (W): 1382 ± 63 Peak Power ($W.kg^{-1}$): 18.1 ± 0.6	Peak Power (W): 1502 ± 55* Peak Power ($W.kg^{-1}$): 19.6 ± 0.6*
Ronnestad et al (2014)	16 elite cyclists (8 national, 8 international)	Lean Lower Body Mass Measurement Maximal Strength test (1RM) 30 second Wingate Sprint Test.	Back Squat Single Legged Leg Press One legged hip flexion Ankle Plantar Flexion. 8-4 reps over 10 weeks.	Peak Power ($W.kg^{-1}$): 23.6 ± 2.9 Mean Power ($W.kg^{-1}$): 10.9 ± 0.9	Peak Power ($W.kg^{-1}$): 24.2 ± 3.4* Mean Power ($W.kg^{-1}$): 10.9 ± 1.1

Key:
Low Repetitions = LR
High Repetitions = HR
Intermediate Repetitions = IntR
Low Load = LL
High Load = HL
Repetition Maximum = RM

Cycling based Strength Development for Athletes.

Traditional resistance training improves force generating capability through changes in muscle architecture and neural sensitivity (Cormie, McGuigan, & Newton, 2011a; 2011b; Jackson et al., 2007; Moss et al., 1997; Ronnestad et al., 2009). However, questions still remain whether resistance exercises with such a high load are the optimal way of causing adaptations in athletes who are required to produce high velocity muscular contractions or cyclic movements such as those seen during sprint cycling. Traditional resistance training exercises have been shown to inherently include a deceleration period towards the end of the range of motion of the exercise across a variety of external loads (Cormie, McGuigan, & Newton, 2011b; Elliott, Wilson, & Kerr, 1989). Analysis of a traditional bench press movement has shown that deceleration can occur for up to 23% of the total movement duration, with this period increasing to 52% of movement duration when external loading is increased to 80% of one repetition maximum (Elliott et al., 1989). Further studies have shown that the use of lighter loads (<45% of 1RM) still elicit a deceleration period of 40-50% of total exercise movement duration (Newton, Kraemer, Hakkinen, Humpheries, & Murphy, 1996). Therefore due to the known deceleration period evident in traditional resistance based exercises it is suggested that similar power production spectrums, like those seen during high velocity sporting movements would not occur, as these sporting movements often have a high and constantly increasing contractile velocity (Cronin et al., 2013; Cronin, McNair, & Marshall, 2001).

The use of sport specific resistance training, where external resistance is applied to the athlete during movements that replicate those actions carried out during sporting performance, have been shown to cause physiological adaptations and overall improvement in athletic performance (Cormie, McGuigan, & Newton, 2011b; Cronin et al., 2013; Koninckx, Van Leemputte, & Hespel, 2010). Recently the use of wearable resistance has shown to cause positive adaptations in power based performance, with jump performance improving as a result of external loading of 7-30% of body mass during sport specific movements (Macadam, Cronin, & Simperingham, 2016). These findings indicate that the use of external resistance during sport specific movements may be of benefit to overall performance. A comparison of the effects that both traditional resistance training and cycle specific training had on maximal power output and endurance cycling performance, showed that the use of isokinetic resistance cycling can elicit similar force production adaptations and overall increases in power output production to that caused by traditional resistance based exercises (Koninckx, Van Leemputte, & Hespel, 2010). During the study nine participants completed two sessions a week of isokinetic ergometer training, in which they are required to perform 4-6 sets of isokinetic sprints (12 crank revolutions per sprint) at a set cadence of 80rpm. Isokinetic ergometer testing carried out at the conclusion of the training period showed an increase in maximal power output of 10-15%. A similar increase was shown in the traditional resistance training group with 11-15% improvement compared to pre training maximal power (Koninckx, Van Leemputte, & Hespel, 2010). Further analysis showed that an improvement in power output from the weight training group was irrespective of crank velocity, while the isokinetic group only improved to a velocity of 120rpm. This suggests that the isokinetic training group had a more sport specific adaptation, as the maximal power output values were produced within a similar range to that of the known optimal pedal rate of 110-130rpm.

Similar improvements in force generating capability and overall improvements of power output production have also been found as a result of isokinetic controlled velocity training (Ewing et al., 1990; Koninckx, Van Leemputte, & Hespel, 2010). A ten week isokinetic training program showed improvements in peak torque and muscular power production of 17.5% and 24.9% respectively (Ewing et al., 1990). Increase in cross sectional muscle fibre size in muscle fibre type IIa (10.1%-13.3%) and type I muscle (13.5%-17.1%) were also found post training (Ewing et al., 1990). From this study it can be suggested that the use of isokinetic training can elicit similar physiological changes to the working muscle architecture, as that caused by traditional strength based weight training. The improvement in peak torque following isokinetic training also indicates that the specificity of isokinetic training for cyclists may be advantageous in improving maximal power production capabilities.

A lack of cycling based strength development research is apparent with no current literature on the effects that isokinetic cycling may have on sprint based cycling performance. Furthermore no research is available regarding the effects that low cadence cycling has on overall power production of cyclists, indicating a significant gap in current knowledge of optimal sprint cycling training prescription.

Conclusion.

An increase in power production has been shown to improve performance in sprint and endurance based cycling. In order for power production to increase either the force application capability or pedaling velocity must be improved, with cycling specific research indicating that if force application can be enhanced and pedaling rate is within the range of optimal pedaling rate then performance will improve. The use of traditional strength training modalities and cycle based strength training have both shown to cause changes in force generating capability and improve overall athletic performance. Traditional resistance training with use of regimented external load programming has shown to cause changes to muscle architecture and muscle fibre contraction properties when prescribed to both untrained and trained individuals. Further investigation is required firstly into the relationship that muscular strength has with power production during sprint cycling. In particular what components of cycle based power are effected by muscular strength? Secondly research into the potential benefits of traditional or cycle based strength development on sprint cycling performance would be of benefit to cycling practitioners who wish to develop power and performance in their athletes.

Chapter Three: "The Relationship between of Muscular Strength and Power Production Capabilities in Trained Track Cyclists"

Preface.

The purpose of this study was to investigate the relationship between muscular strength and power production capabilities in trained track cyclists. Ten participants (Age: 22.1 ± 6.8 years, Sex: 6 female/4 male, Height: 176.1 ± 6.7cm, Weight: 72.1 ± 7.9kg) performed an isometric mid thigh pull assessment and isokinetic sprint assessment. Kinetic and Kinematic variables were measured and the following variables obtained: Peak Force (PF), Peak Rate of Force Development (PRFD), Maximal Torque and Maximal Power (Pmax). Participants showed a strong relationship between PF and peak torque values of all five isokinetic sprints (r = 0.890 - 0.925). Participants also showed a strong relationship between PRFD and maximal torque of all five isokinetic sprints (r = 0.696 - 0.755). No significant relationships were found between muscular force and Pmax produced during isokinetic sprints. The use of an isometric measurement is sufficient in providing an insight into force capabilities of sprint cyclists. Practitioners would be advised to improve overall muscular strength and explosive force capabilities if the desired outcome is to increase torque application and power production during maximal sprint cycling.

Introduction.

The sport of track cycling is seen as a sprint based cycling discipline with athletes required to perform either a maximal single bout sprint or repeated sprint bouts during events ranging from 250m to 30km in length (Craig & Norton, 2001; Martin et al., 2007). In order for athletes to be successful in these events power production must be optimised (Dorel et al., 2005; Gardner et al., 2007; Gardner et al., 2005; Martin et al., 1997; 2007). However tactical and psychological factors may also influence performance regardless of power production optimisation (Menaspa, Abbiss, & Martin, 2013; Ofoghi, Zeleznikow, MacMahon, & Dwyer, 2013; Schumacher et al., 2001). In relation to cycling, power can be defined as the product of torque applied to the pedal surface by the working musculature in relation to the velocity of the rotating crank arm (Emanuele & Denoth, 2011; Martin et al., 2007; McCartney et al., 1985; Samozino et al., 2007). The interaction between torque application and crank velocity is commonly discussed through the force-velocity relationship, with peak power reported to occur when force application to the pedal surface and crank arm velocity are optimised (Emanuele & Denoth, 2011; Fonda & Sarabon, 2010; Martin et al., 2007; Martin, Lamb, & Brown, 2002; Samozino et al., 2007).

During a maximal sprint bout peak power has been reported to occur between 120-140 revolutions per minute (rpm), also known as the optimal pedaling rate of power (Dorel et al., 2005). Literature on optimal pedaling rate has shown that a crank velocity of 120-140rpm is significant in allowing maximal contractile force and contractile velocity of the recruited muscle fibres, while crank velocities higher than 140rpm have shown to negatively impact the ability for forceful contractions of the recruited muscle fibres (Dorel et al., 2005; Gardner et al., 2007; Martin et al., 2007; Martin & Brown, 2009). Sports where power demands are a significant contributing factor to performance have shown that increases in muscular strength are advantageous in improving overall power production capability (Cormie, McGuigan, & Newton, 2011; Izquierdo et al., 2004; Saez de Villarreal et al., 2013). The measurement of muscular force through isometric contraction is one such way in which force production capability can be established for power orientated athletes (Stone et al., 2004). Although the use of isometric strength measures has been criticized as to its specificity in characterizing dynamic power exercises (Stone et al., 2004). However a study by Stone et al (2004) found a strong correlation between isometric strength and cycling success, indicating that an isometric assessment for sprint orientated athletes can be informative.

There is a lack of understanding regarding the relationship isokinetic force production has with maximal power output during short bouts of sprint cycling. Rannama et al. (2012) using an isokinetic dynamometer showed that high levels of isokinetic force produced from the hip, knee and ankle joint had a significant impact on the ability to produce high levels of power during maximal cycling bouts. To better understand the relationship between muscular force and cycling power production attempts should be made to measure isokinetic force of the lower limb joints during a cycling specific movement. Further understanding of the force velocity relationship and optimal pedaling rate phenomenon using trained cyclists would be beneficial to practitioners to aid in gear ratio selection and overall training prescription. Therefore the purpose of this study was to investigate the relationship between muscular force and power production in highly trained sprint cyclists. In addition the study investigated the impact that maximal force had on optimal pedaling rate characteristics.

Methods.

Experimental Approach to the Problem.

This cross sectional study investigated the relationship between maximal force production using an isometric mid thigh pull assessment (IMTP), and maximal torque and velocity characteristics during short maximal cycling sprint bouts on a loaded ergometer. Testing was performed on trained track cyclists and carried out during the track cycling off season.

Subjects.

Ten trained track cyclists (Age: 22.1± 6.8 years, Sex: 6 female/4 male, Height: 176.1 ± 6.7cm, Weight: 72.1 ± 7.9kg) volunteered as participants for this research. All participants had competed in a Track Cycling National Championships or higher level competition within the past twelve months and had experience of gym based resistance training. All participants of this study were free of injury or physical disability that would affect their ability to perform the required tests maximally. Subjects were informed of the risks and benefits of participation in this study and signed informed consent. The Auckland University of Technology ethics committee approved the procedures for this study prior to commencement of data collection.

Methodology.

Prior to testing, all subjects completed a standardized warm up consisting of a five minute stationary bike warm up (TechnoGym, New Zealand) (Level 10, 70rpm) followed by ten repetitions for the following exercises; Body Weight Squat, Push up from knee or feet. Once the standardized warm up had been completed a demonstration was given to each subject of the correct technique and procedure for performing the IMTP assessment. This was followed by a familiarisation period of the IMTP consisting of three trials at 50%, 70% and 90% of perceived maximum exertion to ensure correct technique and an understanding of the requirements for each maximal effort.

Participants then completed three maximal IMTP lasting approximately three to five seconds for each effort (Stone et al., 2004). Before the commencement of each trial participants were instructed to pull as hard and fast as possible. Sufficient recovery of three minutes was prescribed between trials to ensure that maximal effort could be applied during each trial. For the IMTP a force plate (Fitness Technologies, Adelaide) sampling at 600Hz was used to collect kinetic data. The force plate was placed within a specifically built rack (Fitness Technologies, Adelaide), which allowed for a fixed barbell to be placed at a selected height. Barbell height position was determined using previously established bar height protocol by Stone et al (2004) with participants establishing and maintaining a knee angle of 140-145 degrees and an almost near vertical trunk position throughout each trial. For the purposes of this study both peak force (PF) and rate of force development (RFD) were recorded for each trial, with the two highest values of the three trials then averaged out and used for data analysis. The reliability of this test is high in our laboratory with intraclass coefficient correlations (ICC) values for PF > 0.98, and coefficient variations (CV) < 3%. At the completion of the IMTP assessment study participants had twenty minutes of passive recovery before completing the next test.

The second assessment subjects were required to perform was carried out using a Lode ergometer (Lode, Groningen). The ergometer was configured to the exact dimensions (Saddle height, Headset height & Saddle to Headset distance) for the participants own bicycle and the each participant used their own shoes and pedals. A standardised warm up of seven minutes at 70rpm and 100W preceded the on bike power assessment. On completion of the warm up participants rested for two minutes in a passive state. Participants then performed five maximal isokinetic sprints (60rpm, 80rpm, 100rpm, 120rpm & 140rpm) of approximately eight seconds, with three minutes of active recovery (50W) between each sprint. Each sprint was performed from a stationary standing start position, with the participants favored foot placed in the forward position at a preferred crank angle. Subjects were instructed to remain out of the seat throughout each eight-second sprint. Torque and crank arm velocity were measured through strain gauges on the crank. Torque, Pmax and crank arm velocity were used as performance determinants in this assessment. Intra-class correlation coefficients of 0.96-0.98 have been reported for maximal power output and velocity measurements during isokinetic based cycle sprints (Koninckx, Van Leemputte, & Hespel, 2010), suggesting that the use of isokinetic sprint profile test was suitable for this research.

Statistical Analysis.

Data is reported as Mean ± Standard Deviation. Statistical significance for all data was set at $P \leq 0.05$. A Pearson product moment correlation was used to explore the relationships between variables. Correlations of <0.3, <0.5, <0.7, <0.9, <1.0 were considered small, moderate, large, very large and nearly perfect respectively (Hopkins et al,. 2009).

Results.

Means and Standard Deviations for PF, PRFD and Pmax values for all Isokinetic Inertial Ergometer Sprints are displayed in Table 3.1. No significant correlations were found between PF or PRFD and Pmax for each prescribed pedalling rate.

Table 3.1. Maximal Values of Isometric Mid Thigh Pull Assessment & Inertial Ergometer Sprint Test.

	Isometric Mid Thigh Pull (N)		***Inertial Ergometer Sprint Test (W)***				
	PF	PRFD	60rpm	80rpm	100rpm	120rpm	140rpm
Grouped.							
Mean	2139	11318	1137	1187	1294	1222	1145
SD	710	8083	68	259	332	345	344
Male.							
Mean	2212	12387	1157	1457	1603	1541	1432
SD	1009	7226	2	81	77	66	150
Female							
Mean	2091	10677	1125	1044	1109	1033	978
SD	655	8592	88	207	274	294	319

Key:

Isometric Peak Force = PF

PRFD = Peak Rate of Force Development

Pmax was shown to be a parabolic function of crank velocity with maximal power increasing in relation to crank velocity during the 60rpm and 80rpm isokinetic sprints, before reaching a maximum at 100rpm and decreasing at a similar rate during 120 and 140rpm isokinetic sprints. Maximal power ranged from 843W to 1692W, with all peak power values occurring during the 100rpm isokinetic sprint.

All subjects showed an inverse relationship between peak torque and pedal crank velocity. Highest peak torque values were found during the 60rpm isokinetic sprint and ranged from 167N to 261N (Table 3.2 & Table 3.3). Group maximal torque values for each inertial ergometer sprint are outlined in Table 3.2. Significant correlations were found between PF and maximal torque values for all five isokinetic sprints (Table 3.4). The correlations between PRFD and maximal are also shown in Table 3.3.

Table 3.2. Maximal Torque Values for Isokinetic Sprint Test.

	60rpm	80rpm	100rpm	120rpm	140rpm
Mean	189.9	181.6	159.5	134.0	116.9
SD	48.3	45.9	41.2	33.3	31.7

Table 3.3. Individual Values for Maximal Torque and Crank Velocity Relationship.

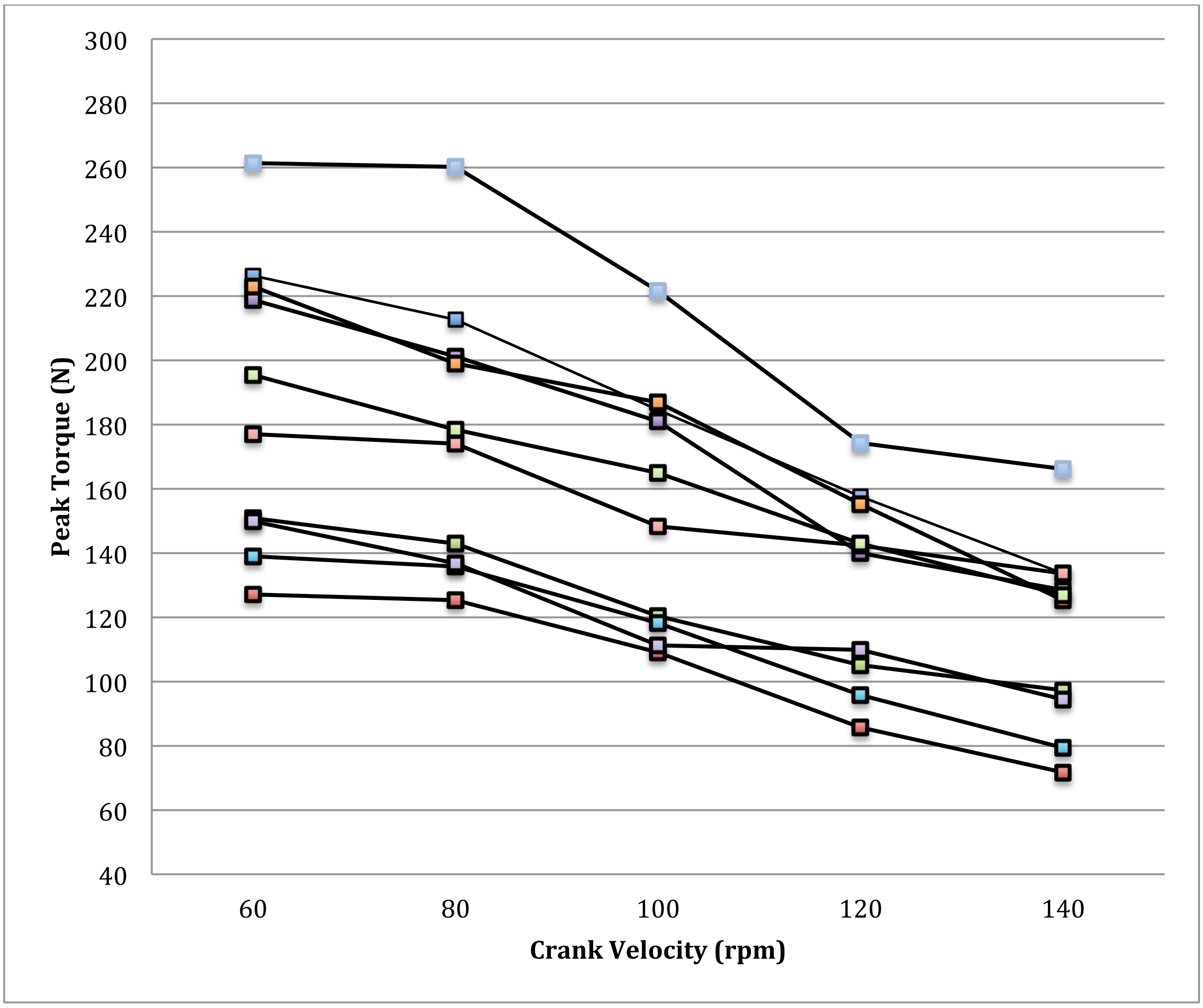

Table 3.4. Correlations of maximal strength values with maximal torque and power values.

	Peak Force	PRFD
Torque 60rpm	0.907*	0.733
Torque 80rpm	0.925*	0.751
Torque 100rpm	0.889*	0.696
Torque 120rpm	0.892*	0.741
Torque 140rpm	0.890*	0.755
Power 60rpm	0.533	0.588
Power 80rpm	0.117	0.275
Power 100rpm	0.198	0.385
Power 120rpm	0.167	0.381
Power 140rpm	0.207	0.485

* = Significant correlation ($p \leq 0.05$)

Discussion.

Results of the current study showed that power production during maximal sprint cycling bouts is significantly influenced by an individual's level of muscular strength. The strongest correlations were found between PF and maximal torque values produced during the 60rpm and 80rpm isokinetic sprint (r = 0.907 and 0.925). The highest torque values (189N) also found during the 60rpm isokinetic sprint. The high maximal torque values produced during the 60rpm isokinetic sprint can be suggested to be the result of the increased maximal strength required to overcome the high relative load applied to the ergometer fly wheel, compared to the higher velocity isokinetic sprints which would have a smaller relative load to overcome. Correlations between PF and maximal torque application were also found during the high velocity isokinetic sprints of 100, 120 & 140rpm (r = 0.889, 0.892 and 0.890 respectively), although maximal torque values were less than that seen during the low velocity isokinetic sprints. This indicates that while there is still a significant requirement for muscular strength to produce torque to the rotating crank arm, the level of effort or requirement of muscular strength is far less than that that required during the low velocity sprints. Previous literature on the effect that inertial loading has on torque application has shown that maximal torque is reduced as a result of a decreasing moment of inertia caused by an increase in crank velocity (Hansen, Jorgensen, Jensen, Fregly, & Sjogaard, 2002). The correlations found between PF and maximal torque during sprint cycling within the present study provide greater understanding of the ability to apply muscular force to produce high levels of power during maximal sprint cycling. Only one previous study has examined this relationship within trained sprint cyclists (Stone et al., 2004). The relationship between maximal torque production capability and crank velocity identified within the current study further supports findings regarding the force-velocity relationship in trained and untrained cyclists.

Significant correlations were found between PRFD during isometric strength assessment and torque values produced during the five isokinetic sprints. This is consistent with findings of Stone et al (2004) and indicates that the rate in which force can be applied significantly impacts on maximal torque values, and consequently maximal power output. Although caution should be taken when applying the PRFD findings, as previous studies have shown poor reliability for these measures (ICC < 0.80) (James, Roberts, Haff, Kelly, & Beckman, 2017; Stone et al., 2004).

Interestingly the findings of the present study found no significant correlations between Pmax achieved during the isokinetic sprints and PF. This is in contrast to Stone et al (2004) who reported a significant relationship between PF and peak power. All participants of the study achieved maximal power during the 100rpm isokinetic sprint, a crank velocity that falls below the range established for the optimal pedaling rate of power (110-130rpm) (Gardner et al., 2007; Martin et al., 2007). Power profiles of all study participants followed a parabolic curve of power indicating that whilst maximal power was achieved outside of the established optimal pedaling rate, the values produced during the 100rpm isokinetic sprint were a true indicator of maximal power. The low maximal power output and optimal pedaling rate found in this study compared to other cycling specific studies Martin, Wagner, & Coyle, 1997; Sargeant, Hoinville, & Young, 1981; Samozino et al., 2007) could be the result of the variance in overall training experience, with subject population of this study having on average 1.8 ± 1.1 years of structured cycling specific training. Studies have shown that a lack of high velocity training or velocity specific training can significantly impact on the ability of the working musculature to produce force at high contractile rates (Cormie, McGuigan, & Newton, 2011; Cronin et al., 2013). This suggests that a possible lack of training or lack of experience in the area of high velocity training within the current subject pool due to the limited time carrying out structured training may have resulted in a lack of power application during the high velocity isokinetic sprints.

Practical Applications.

The findings suggest that muscular strength directly influences torque application at any pedalling velocity during maximal sprint cycling bouts. This is an important finding as previous cycling specific literature has suggested that in order for cycling power production to be improved, either torque or velocity capabilities must be improved. The current study suggests that if muscular strength were to be improved in track cyclists, this could increase maximal torque application at a range of different pedalling rates.

While the present study has shown a significant relationship between muscular strength and torque production capabilities in maximal sprint cycling, the findings also indicate that an increase in torque alone may not be sufficient to improve maximal power levels. The use of high velocity training to improve contractile rates, would most likely improve power production during higher velocity sprint cycling resulting in maximal power being achieved within the optimal pedalling rate of power. It is suggested that when designing training sessions for the purposes of improving sprint performance in a track based cyclist, practitioners would be best to prescribe sessions in which maximal force or maximal acceleration is required. The use of specific velocity training at velocities desired during performance could also be advantageous in improving power capabilities at a given pedalling rate.

Chapter Four: "The effects of Traditional Strength Training vs. Isokinetic Cycle Training on Force Application and Power Production Capabilities in Trained Track Cyclists"

Preface.

The purpose of this training study was to compare the effects of traditional and cycling specific resistance training programmes on muscular strength and power production capabilities in trained sprint cyclists. A total of eight individuals (Age: 21.2 ± 6.6 years, Sex: 6 female/2 male, Height: 173.8 ± 6.3cm, Weight: 67.3 ± 8.1kg) were grouped into either traditional resistance training (*n=4*) or isokinetic cycling training (*n=4*) prior to commencement of data collection for the cross over training study. Participants performed two training sessions a week for two weeks in each training modality, with a one week period of no resistance training between modalities. Testing included an IMTP and an Isokinetic Ergometer Sprint Assessment, carried out at the beginning and completion of each training modality (0, 2, 3, 5 weeks). No significant improvements in muscular strength or power production capabilities were found as a result of either the traditional resistance training or isokinetic cycle based training programmes, with strength levels remaining relatively the same throughout the study. This suggests that the use of both training modalities should be used as training tools in order to maintain power production capabilities, with further research required using prolonged training periods.

Introduction.

The ability for practitioners to correctly prescribe training modalities that are sport specific and cause physiological adaptations conducive to performance are vital regardless of training level (Graham, 1998; Cronin & Crewther, 2004). As sprint cycling performance is dependent on an individuals ability to produce high levels of maximal and sustained power (Dorel et al., 2005; Gardner et al., 2005; Martin et al., 2007), training must as a result cause positive adaptations to the physiological factors contributing to power production. Power can be defined in a cycling context as torque application to the pedal surface in relation to the velocity of the rotating crank arm (Emanuele & Denoth, 2011; Martin et al., 2007; McCartney et al., 1985; Samozino et al., 2007), with changes to either of this components significantly contributing to a change in overall power output (Emanuele & Denoth, 2011;

Gardner et al., 2007; Martin et al., 2007; McCartney et al., 1985).

The use of resistance training in power orientated sports to develop muscular strength is a common approach, with a strong relationship between increases in muscular strength contractile power during dynamic exercises reported (Campos et al., 2002; Cormie, McGuigan, & Newton, 2011b; Moss et al., 1997). Traditional resistance training for athletic performance has shown that external loading of greater than 60% of 1RM is sufficient to cause changes to the muscle architecture and overall power generating capability of the worked musculature (Cormie et al., 2007; Cormie, McGuigan, & Newton, 2011b; Saez de Villarreal et al., 2013). While the use of low load resistance training (<40% 1RM) has shown to cause increased neural response adaptations resulting in increased power output of the contracting muscle (Cormie, McGuigan, & Newton, 2011b; Cronin et al., 2013). Regardless of the external load used during traditional resistance training exercises a deceleration period is found to occur, significantly impacting the ability of the contracting muscle to produce maximal force (Elliott et al., 1989; Newton et al., 1996). As a result researchers and practitioners have suggested prescribed exercises should elicit similar joint range of motions and contractile rates to that of the desired sporting movement (Cormie, McGuigan, & Newton, 2011b; Cronin et al., 2013).

Within cycling contexts the use of isokinetic cycling training has been used as a form of cycling specific strength training, and a method for developing power at specific pedalling rates (Koninckx, Van Leemputte, & Hespel, 2010b). The prescription of low velocity isokinetic training on trained cyclists has been shown to cause improved sustained power production (Koninckx, Van Leemputte, & Hespel, 2010b), while changes in muscle architecture have also been reported using isokinetic based training (Ewing et al., 1990).

Currently there is little research regarding optimal training for sprint cyclists, with varying findings and recommendations found from either traditional or isokinetic training based studies (Rannama et al., 2013; Koninckx, Van Leemputte, & Hespel, 2010). To date there is only one study examining the contrasting effects of traditional versus isokinetic training on endurance based cyclists (Koninckx, Van Leemputte, & Hespel, 2010). No studies appear to have examined the effects of these training modalities on sprint based cycling performance. The purpose of this study was to examine the effects that both traditional resistance based strength training and isokinetic cycle based strength training has on sprint cycling performance.

Methods.

Experimental Approach to the Problem.

This crossover training study investigated the effects that a traditional gym based strength program and a cycle based strength programme had on the force and power characteristics of trained track cyclists. Participants of the study were divided into two groups prior to commencement of study. Each group then participated in a 2 week training block of either traditional or isokinetic resistance training. This was followed by one week of active recovery. Participants then completed a further 2 weeks of resistance training in the opposite modality to that of the first training block.

Subjects.

Eight national level track cyclists (Age: 21.4 ± 6.6 years, Sex: 6 female/2 male, Height: 173.8 ± 6.3cm, Weight: 67.3 ± 8.1kg) who had participated in a national track cycling championships within 12 months of the start of study volunteered as participants for this training study. Each participant signed an informed consent form prior to participation. The Auckland University of Technology Ethics Committee granted approval for all procedures of this study. All participants of this study were free of injury or physical disability that would affect their ability to perform the required tests maximally.

Methodology.

Testing Procedures.

Prior to testing, all subjects completed a standardized warm up consisting of a five minute stationary bike warm up (TechnoGym, New Zealand) (Level 10, 70rpm) followed by ten repetitions for the following exercises; Body Weight Squat, Push up from knee or feet. Once the standardized warm up had been completed a demonstration was given to each subject of the correct technique and procedure for performing the IMTP Assessment. This was followed by a familiarisation period of the IMTP Assessment consisting of three trials at 50%, 70% and 90% of perceived maximum exertion to ensure correct technique and an understanding of the requirements for each maximal effort.

Participants then completed three maximal trials of IMTP lasting approximately three to five seconds for each effort. Sufficient recovery of three minutes was prescribed between trials to ensure that maximal effort could be applied during each trial. For the IMTP Assessment a force plate (Fitness Technologies, Adelaide) sampling at 600Hz was used to collect kinetic data. The force plate was placed within a specifically built mid thigh pull rack (Fitness Technologies, Adelaide) which allowed for a fixed barbell to be placed at a selected height. Barbell height position was determined using previously established bar height protocol by Stone et al (2004) with participants establishing and maintaining a knee angle of 140-145 degrees and an almost near vertical trunk position throughout each trial. For the purposes of this study both PF and PRFD were recorded for each trial, with the best two of three trials used for data analysis. The reliability of this test is high in our laboratory with ICC values for PF > 0.98, and CV's < 3%. At the completion of the IMTP assessment study participants were instructed to perform twenty minutes of passive recovery.

The second assessment subjects were required to perform was carried out using a Lode ergometer (Lode, Groningen). For each subject the ergometer was configured to the exact dimensions (Saddle height, Headset height & Saddle to Headset distance) of the participants own bicycle and each participant used their own shoes and pedals. A standardised warm up of seven minutes at 70rpm and 100 watts preceded the on bike power assessment. On completion of the warm up participants rested for two minutes in a passive state. Participants then performed five maximal isokinetic sprints (60rpm, 80rpm, 100rpm, 120rpm & 140rpm) of approximately eight seconds, with three minutes of active recovery (50W) between each sprint. Each sprint was performed from a stationary standing start position, with the participants favored foot placed in the forward position at a preferred crank angle. Subjects were instructed to remain out of the seat throughout each eight-second sprint. Torque and crank arm velocity were measured through strain gauges on the crank, with Pmax and crank arm velocity used as performance determinants in this assessment. ICCs of 0.96-0.98 have been reported for maximal power output and velocity measurements during isokinetic based cycle sprints (Koninckx, Van Leemputte, & Hespel, 2010b).

Training Procedures.

Throughout the duration of data collection participants were asked to record each workout completed. Participants recorded training sessions via Training Peaks online training software (TrainingPeaks LLC, Bolder), with session type and session duration recorded. Total weekly training time (hours) and session types were gathered for each participant and then calculated into group averages. For the duration of the data collection period participants were instructed not to complete any gym or ergometer resistance sessions other than those prescribed to them by the researcher. This was confirmed by visual observation of training diaries.

Traditional Gym Based Strength Training:

Gym based training was carried out twice a week for four weeks under the supervision of the lead researcher. The exercises were selected due to similar joint range of motions to that seen during a cycle pedal stroke. Exercises included: Back Squat to Box, Single Legged Leg Press, Deadlift and a Single Legged Box Step Up. Prescribed loads were 80-85% of the predicted 1RM for each exercise, and each exercise consisted of four sets of four repetitions (Table 4.1). During the first session all participants carried out a familiarisation session to ensure the following: 1) Participants were able to perform each exercise with correct technique; 2) Participants were able to perform each exercise with no discomfort that may lead to injury; 3) To gain an understanding of correct loading for each exercise in accordance with the 80-85 1RM load range.

Table 4.1. Traditional Resistance Training Programme.

Exercise	Repetitions	Sets	Load (1RM %)	Rest Period
Back Squat to Box	4	4	85%	3min
Single Legged Box Step Up	4	4	80%	3min
Barbell Deadlift	4	4	85%	3min
Single Legged Leg Press	4	4	80%	3min

Isokinetic Cycle Training:

Isokinetic Cycle training was carried out twice a week for four weeks under the supervision of the lead researcher. Each training session consisted of five maximal isokinetic sprints of which each sprint consisted of 12 full pedal revolutions at 80rpm. Four minutes of recovery was prescribed between each sprint and was carried out in an active state of pedaling with no resistance at 70rpm. Participants also followed a prescribed warm up & warm up protocol.

Statistical Analysis.

Means and standard deviation were determined for isometric PF, PRFD and peak power output. Standardized changes in the mean of each measurement pre to post were used to assess the magnitude of effects, with ES of <0.2, 0.2-0.6, 06-1.2, 1.2-2.0 considered trivial, small, moderate and large respectively (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results.

For the duration of the study all participants completed 10.7 ± 3.0 hours a week of training. Training consisted on average of 3-4 low intensity bicycle based sessions and 2-3 track specific training sessions (either track or ergometer training).

Mean and Standard Deviations for PF and PRFD for each data collection point are displayed in Table 4.2. PF was found to increase slightly as a result of the traditional gym based strength training (Pre = 2012.2N vs. Post = 2062.9N), while isokinetic training resulted in a slight decrease in PF (Pre = 1916.3N vs. Post = 1848.5N). The changes found in PF from pre training intervention to post training intervention were not meaningful for either gym based strength training (ES = 0.06) or isokinetic cycle training (ES = -0.12). No meaningful changes were found in PRFD as a result of gym or cycle based strength training.

Table 4.2 Maximal Values of Isometric Mid Thigh Pull Assessment.

	Traditional Gym Based Strength Training.				Isokinetic Cycle Based Strength Training.			
	Pre Training.		Post Training.		Pre Training.		Post Training.	
	PF	PRFD	PF	PRFD	PF	PRFD	PF	PRFD
Mean	2012.2	10646.9	2062.9	10568.6	1916.3	9733.3	1848.5	9412.7
SD	789.0	3837.5	784.0	3870.4	579.5	3512.0	592.0	3470.9

Changes in maximal torque and Pmax as a result of each training modality for each isokinetic sprint are shown in Table 4.3. Little or no change were found in maximal torque or Pmax as a result of both training modalities. The changes seen between pre and post testing as a result of either traditional (ES=0.02) and isokinetic training (ES=0.09) were trivial.

Table 4.3. Maximal Torque & Power values of Isokinetic Sprint Test.

	Traditional Gym Based Strength Training.				**Isokinetic Cycle Based Strength Training.**			
	Pre Training.		Post Training.		Pre Training.		Post Training.	
	Torque (N)	Pmax (W)	Torque (N)	Pmax (W)	Torque (N)	Pmax (W)	Torque (N)	Pmax (W)
60rpm	200.7	1099.8	201.3	1094.0	200.2	1083.3	199.9	1079.5
SD	47.0	113.4	45.4	99.9	48.1	56.1	47.4	97.5
80rpm	184.6	1161.0	185.5	1168.9	183.8	1160.1	185.1	1163.3
SD	44.6	200.1	43.8	152.1	41.9	170.7	40.7	231.8
100rpm	171.2	1262.6	169.4	1250.5	163.7	1247.9	165.0	1244.7
SD	39.3	159.9	43.5	184.3	38.3	203.2	40.3	220.0
120rpm	152.5	1254.3	151.1	1256.1	144.1	1254.9	139.9	1254.0
SD	41.1	277.7	42.8	250.0	40.4	248.7	37.9	299.2
140rpm	132.1	1152.0	132.4	1152.8	127.1	1125.8	127.2	1130.2
SD	35.9	341.8	38.5	313.8	36.3	300.9	39.1	295.7

Discussion.

Findings from the current research have shown no meaningful changes in muscular strength or performance as a result of short-term traditional or cycling specific training modalities. The findings of the present study are in contrast to previously reported literature, with power production capabilities of trained endurance cyclists showing significant improvement as a result of both traditional and isokinetic strength training modalities (Koninckx, Van Leemputte, & Hespel, 2010). The contrast in results between the current study and previously established results is no doubt as the result of varying data collection periods, with Koninckx et al (2010) prescribing a 12 week training programme. This is compared to the two week training blocks within the current study. It appears that a training period of this magnitude is insufficient in eliciting physiological adaptations as a result of either traditional or isokinetic cycling strength training. Two to three sessions per week for a period of four to six weeks is commonly reported as a significant period to cause adaptations in muscle architecture, muscle power and overall strength capabilities (Adams, O'Shea, O'Shea, & Climstein, 1992; Cormie, McGuigan, & Newton, 2011; Wilson, Newton, Murphy, & Humpheries, 1993). This further supports the assumption that the current period of two weeks was insignificant to cause changes in the measured areas.

Although no significant improvements were found in PF, maximal torque or Pmax capabilities as a result of the training interventions, it should be noted that performance did not significantly decrease as a result of either traditional or isokinetic strength training. Koninckx et al (2010) found after 12 weeks of isokinetic training power production had improved at lower cadences, with no change found at cadences at or above 120rpm. This was in contrast to the traditional resistance training subjects who increased Pmax at all given cadences. Taking into consideration these findings and the results of this training study it can be suggested that the use of both isokinetic and traditional resistance training is applicable for sprint cyclists to maintain power production capability. While longer training periods than that of the current study for each training modality is most likely required to elicit improvements in Pmax output.

Further investigation is required into the prolonged effects of traditional and isokinetic cycle based training on power production capabilities and performance within sprint orientated track cyclists. Future research should use a similar study design to that of the current study and should implement a 4-6 week period for each training block, as well as a significant period of active recovery between modalities. An increase in the number of recorded performance measures such as pedalling efficiency and left/right leg ratios would also add to the depth of future studies.

Practical Applications.

The findings of this study suggest that both forms of resistance training are useful tools in maintaining muscular strength and overall power production capabilities, especially when considered in the wider context of previously established literature. Furthermore, the results of the isokinetic training intervention show this form of training does not have an adverse effect on sprint cycling performance in regards to the measured performance variables within the current studies. This is an important finding for sprint cycling practitioners as specific on bike resistance work does not need to be sacrificed in order to prescribe further traditional resistance training sessions.

However practitioners when applying isokinetic strength training should take caution, as it is still unclear if this type of training is capable of improving power generating capability in sprint cyclists or if it should only be used as a power maintenance training tool. Further research on traditional vs. isokinetic training using prolonged training periods is required to better understand the physiological adaptations. Therefore it is recommended that until this research is carried out a combination of traditional and isokinetic strength training should adopted to improve muscular strength.

Chapter 5: General Discussion and Practical Applications.

General Discussion.

As a result of the literature review examining the effects and development of strength on power output characteristics in sprint cyclists, it was established that the use of resistance training is sufficient in improving power generating capabilities of both trained and untrained individuals (Cormie et al., 2007; Cormie, McGuigan, & Newton, 2011b; Moss et al., 1997). Changes to muscle architecture, mainly increases in muscle fibre size and muscle fibre recruitment have shown to increase contractile force levels within the recruited musculature (Cormie, McGuigan, & Newton, 2011b; Moss et al., 1997; Putman et al., 2004). While increased neural sensitivity and improved contractile rates of the contracting musculature have also been shown to improve force generating capability (Cormie, McGuigan, & Newton, 2011b). Based on the literature, it seems that if changes can be made to the architecture of the recruited muscles then force application to the pedal surface could be increased. This would be advantageous in a sport such as track cycling where torque application is a significant factor of the force velocity relationship of power.

The findings of this thesis have shown that while no significant relationship was found between an increase in muscular force and maximal power production capabilities, there was a positive relationship found between muscular strength and maximal torque production. As torque is regarded as the main product contributing to power production (Martin et al., 2007; McCartney, Obminski, & Heigenhauser, 1985; Samozino, Horvais, & Hintzy, 2007), it would seem logical that increases in torque as a result of increased muscular force would in turn result in increased power production. As this was not the case in the present study it can be suggested that in order to maximize power production an individual must be able to achieve optimal pedaling rate, regardless of maximal torque application. This is highlighted in previous literature with results showing maximal power being achieved close to 120rpm (McCartney, Obminski, & Heigenhauser, 1985; Samozino, Horvais, & Hintzy, 2007), in comparison to maximal power being achieved at 100rpm in the present study.

To increase torque and consequently improve power production generating capability during maximal sprint efforts, adaptations within the working musculature is required to take place (Cormie et al., 2007; Cormie, McGuigan, & Newton, 2011b). Previous literature on the effects of traditional and isokinetic strength training modalities on endurance cyclists has shown increases in mean power output during a prolonged cycling assessment as a result of both training modalities (Koninckx, Van Leemputte, & Hespel, 2010a). Improved maximal torque application at low cadence velocities as a result of isokinetic training was also examined within endurance based cyclists (Koninckx, Van Leemputte, & Hespel, 2010). The short term training study found no significant improvements in power production capabilities as a result of either traditional or isokinetic based strength training. The differing training protocols between studies, specifically the duration of each training period, would explain these conflicting results. Within the current research if a training period of 4-6 weeks for each training modality had been prescribed, compared to the current 2 week period then it could be expected that similar results to Koninckx et al (2010) may have been seen.

Practical Applications:

- Practitioners should look to develop muscular strength in track cyclists to improve maximal torque output during maximal sprint cycling. For example if force capability can be improved through strength training using a range of different training modalities this would directly improve torque capabilities at a range of different cadence ranges required in the field of sprint track cycling.
- The use of an isometric lab based assessment such as the IMTP is a useful tool in analysing sprint cycling performance. As a result practitioners could use an isometric assessment to gain a better understanding of the force capabilities of sprint athletes and how an individuals muscular force levels relate to power production. If an athlete had a high level of muscular force, but low relative power profile this may indicate that specific velocity training is required.
- Profiling a track cyclist through the use of torque and velocity assessment allows practitioners to analyse the capabilities of both muscular force and limb velocity within a controlled cyclic movement to determine if an athlete is dominant or limited in one or both of these areas. Thus allowing practitioners to prescribe either force or velocity specific training to improve power output at optimal pedaling rates.
- The use of traditional gym based strength training and isokinetic cycle strength training are beneficial for sprint and endurance based athletes, with performance either sustained or increased as a result of these training modalities. Practitioners would be best to prescribe a combination of these two modalities throughout a periodisation plan.

Recommendations for future research.

As a result of the limitations within this research it is still not known what effects traditional and isokinetic strength training has on the physiological factors contributing to sprint cycling performance. Further investigation into the application of traditional and isokinetic training protocols using longer training periods (4-6 weeks) would be of benefit to practitioners to determine the physiological effects and performance effects of each modality on sprint based cyclists. Using training periods longer than that of the current study could also allow researchers to investigate the effects that differing physiological stimuli produced from each training modality has on overall training load. Should this be determined, it may significantly influence session structure and frequency for both untrained and trained individuals.

A comparative analysis of traditional and isokinetic training on elite vs. sub elite sprint cyclists would also be of benefit for future researchers and practitioners to determine if the physiological responses to training differ between trained and untrained individuals. Within group analysis could also be performed using these groups to determine possible differences between male and female athletes through a spectrum of different training levels.

Research Limitations:

- Small sample size for the training study.
- Due to time constraints the training study was required to be altered from the proposed period (two 4 week training periods, 2 week washout period) to the present structure (two 2 week training periods, 1 week washout period).
- The training study had no control group.

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Appendix 1

A U T E C
S E C R E T A R I A T

18 May 2015

Mike McGuigan
Faculty of Health and Environmental Sciences

Dear Mike

Re Ethics Application: **15/109 The effects of strength development on power production capabilities and performance of sprint track cyclists.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 18 May 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 18 May 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 18 May 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee
Cc: James Vercoe jvercoe@aut.ac.nz

Appendix 2

Participant Information Sheet

Date Information Sheet Produced:

14/5/2015

Project Title

The effects of strength development on power production capabilities and performance of sprint Track Cyclists in Auckland.

An Invitation

I, James Vercoe, am a Masters student based at the Sports Performance Research Institute New Zealand (SPRINZ) at AUT-Millennium, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study to assess changes in strength and power levels of trained sprint cyclists as a result of gym and bike based strength training. Participation is entirely voluntary and you may withdraw at any time prior to November 30th 2015 when the data collection is completed without any adverse consequences.

What is the purpose of this research?

The purpose of this study is to investigate the changes in strength and power production capabilities as a result of participating in two four week training blocks focusing on either gym or bike specific strength development. This study is being conducted as part of my Master of Sport and Exercise Science degree.

How was I identified and why am I being invited to participate in this research?

You were identified as a participant for this research as you are an experienced track cyclist between the ages of 16-35 years and you have participated in a recent national track cycling championships.

Exclusion criteria includes any current injuries, or in the past six months which have hindered or stopped normal participation in cycling training or racing.

What will happen in this research?

You will be assessed on three occasions in total with each testing session lasting approximately 90 minutes. The sessions will take place at the SPRINZ Strength and Conditioning Laboratory at AUT-Millennium. The first session will include a familiarization with all testing equipment and protocols prior to data collection, with subsequent sessions only including data collection. Each session will involve having your height and weight measured. Thereafter you will go through a series of tests including an isometric strength test, an on bike strength test and on bike power test. Each of these tests involves you producing a maximal effort 2-3 times for around 5 seconds. There will be a total of two testing sessions which will be approximately 90 minutes in duration.

After the testing session you will be placed in either a gym or cycling based training group. You will then complete two training sessions a week for four weeks specific to your training group type, before crossing over and completing a further four weeks of training in the other training group. Gym based training will involve three to five sets of traditional resistance training exercises (back squat, single legged leg press, deadlift & step ups). Cycling based training will involve a number of maximal efforts of eight seconds on an isokinetic ergometer limited to a low cadence rate. The second testing session will be carried out at the end of the first 4 weeks of training and prior to commencing the second four week training block, while the final testing session will be carried out at the end of the 8 week training study. Each training session will be approximately 90 minutes in duration. There will also be an additional 90 minute testing session at the completion of each of the training periods.

What are the discomforts and risks?

There are minimal anticipated discomforts and risks from participating in this testing and training. The training induced discomfort and fatigue will be similar to or less than that of your regular cycling training sessions. You may experience some mild fatigue; this response is normal and triggered by the onset of any exercise. The other possible discomfort is delayed onset muscle soreness on the day following or two days after testing and/or training.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the testing procedures and throughout the procedure every effort will be made to minimize discomfort.

If you do not feel you are able to complete the testing requested, you should notify the researcher immediately and the testing will be terminated.

Finally, you should notify the researcher, if you have a current or previous injury that might affect your performance, or that might be worsened or aggravated by the required activity. For example, any strains and sprains must be reported, specifically to the hip, knee and ankle.

Prior to any training sessions you will be provided with nutritional information (before and after best practice), asked to bring a water bottle and the appropriate gear (covered shoes, cycling shoes, breathable clothing and towel). To avoid injury and facilitate recovery all training sessions will include a warm-up and cool down, and emphasis will be placed on correct technique.

What are the benefits?

By participating in this study, you will receive information about your cycling performance ability and develop your understanding of how gym and on bike based training can help you improve your cycling ability. You will also improve our understanding of how traditional strength training compares to sport specific strength development on the bike, which will improve the practice of strength and conditioning specialists and coaches. Ultimately it is hoped that the findings will improve current high performance practices.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The findings of the research may be used in future publications. The identity and individual results of each participant will be kept confidential. Only my primary supervisor (Prof. Mike McGuigan), and I will have access to, and analyze your results

What are the costs of participating in this research?

Costs to participate is minimal and only requires scheduling your time to be available for testing and training (90 minutes for each testing and training session for a total of 30 hours over approximately 10 weeks). Petrol vouchers will be provided to assist with transport costs.

What opportunity do I have to consider this invitation?

A response to this invitation would be appreciated by no later than the 30th of June 2015.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to myself prior to participating in any of the tests.

If at any stage after volunteering, you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any time without any prejudice prior to the completion of data collection on November 30th 2015.

Will I receive feedback on the results of this research?

Yes, you can receive a summary of individual results once the information is ready for distribution (around one month after completing the study). Please check the appropriate box on the *Consent Form* if you would like this information. After the completion of the study you will be invited to an information session at AUT-Millennium where we will present the main findings of the study. You will also have the opportunity to ask the researcher any questions you have about your individual results.

The results of your testing performance will only be given to your coach with your permission (please check the appropriate box on the *Consent Form*).

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, or mobile 021 605 179

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

James Vercoe; email: jvercoe@aut.ac.nz; mobile: 021614380

Project Supervisor Contact Details:

Supervisor, Prof. Mike McGuigan; email: michael.mcguigan@aut.ac.nz or mobile: 021 605 179

Appendix 3.

Consent Form	

Project title: ***"The effects of strength development on power production capabilities and performance of sprint track cyclists in Auckland"***

Project Supervisor: **Professor Michael McGuigan**

Researcher: **James Vercoe**

○ I have read and understood the information provided about this research project in the Information Sheet dated 14th May 2015.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I am not suffering from any illness or injury that impairs my physical performance, or any psychological disorder that may impact on my ability to understand what is required of me during the research process.

○ I agree to have height and weight measurements recorded during all testing sessions, as well as participating in lower limb strength and power test measurements.

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research (please tick one):
Yes○ No○

Participant's signature:
………………………………………………………………………………………………

Participant's name:
………………………………………………………………………………………………

Participant's Contact Details (if appropriate):
………………………………………………………………………………………
………………………………………………………………………………………

Date:

Approved by the Auckland University of Technology Ethics Committee on 18th May 2015, AUTEC Reference number 15/109

Note: The Participant should retain a copy of this form.