BE WHAT YOU WANT TO BE

CQUniversity

CQUniversity AUSTRALIA

The Effect of Concurrent Resistance and Sprint Training on Health and Performance in Masters Road Cyclists

Luke Del Vecchio
Bachelor of Science (Exercise Science) Wollongong University
Master of Exercise Science (Strength and Conditioning)
Edith Cowan University

School of Medical and Applied Sciences
Central Queensland University

Primary Supervisor: Associate Professor Peter Reaburn
Associate Supervisor: Marko Korhonen

A thesis by published works submitted for the degree of Doctor of Philosophy

July 2016

Abstract

The well established guidelines for developing speed and power in younger athletes may not apply to masters athletes due to a number of age-related changes in muscle morphology and neural factors affecting speed and power. These age-related changes include decreased muscle mass, a decrease in type II muscle fibre size, and decreased neural activation of muscle. These age-related declines strongly suggest concurrent sprint and resistance training may be required to improve speed and power in masters athletes. However, limited research has examined the impact of concurrent sprint and resistance training on sprint performance in masters athletes. Moreover, no studies to date have investigated the potential health benefits of concurrent resistance and sprint training in masters athletes. Indeed, the majority of research into age-related declines in sprint performance in masters athletes has examined track sprint runners with no research to date having examined masters cyclists, a growing cohort in masters sport. Furthermore, few studies have examined the effect of either sprint training and/or resistance training on sprint performance and/or health in masters cyclists.

Through a series of five related papers, three of which have been published and two in review, the present thesis has five main aims: 1) to critically review the previous research examining the effectiveness of resistance training on sprint and endurance performance in masters athletes; 2) to use the available research to develop a concurrent resistance and sprint cycling training program with the goal of improving sprint cycling performance in male masters road cyclists; 3) to determine the reliability of a commonly-used battery of explosive muscular power tests in male masters athletes; 4) to examine the influence of concurrent resistance and sprint cycling training on cardiometabolic risk factors in male masters road cyclists; and, 5) to examine the effect of concurrent sprint cycling and

resistance training on muscular strength, muscular power and sprint performance in male masters road cyclists.

In manuscript 1, entitled "The effects of resistance training on sprint and endurance performance in masters athletes: a narrative review" (published in *The Journal of Fitness Research*), four previously published studies informed a narrative review examining the effects of resistance training on sprint and endurance performance in masters athletes. The review highlighted positive outcomes of both resistance and sprint training on sprint performance in masters sprint runners. Manuscript 2 entitled "Concurrent resistance training and flying 200-meter time trial program for a masters track cyclists" (published in *Strength and Conditioning Journal*) describes the rationale and structure of a concurrent resistance and sprint cycling program designed to improve muscular strength and power and sprint performance in masters road cyclists. This published review formed the basis for studies reported in manuscripts 4 and 5 below. Manuscript 3 entitled "Reliability of squat jump and countermovement jump performance in masters athletes" (published in *La Prensa Medica Argentina*) describes the test-retest reliability of the squat and countermovement jump tests and associated measures in male masters athletes. Excellent test-retest reliability was observed for absolute and relative peak power for both the squat jump and countermovement jump tests reported and used in Manuscript 5 below. Manuscript 4 entitled "Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists (published in the *Journal of Exercise Rehabilitation*) describes the effect of 12-weeks of concurrent resistance and sprint cycling training on cardiometabolic risk factors in masters road cyclists. The findings suggest replacing a portion of endurance cycling with 12-weeks of concurrent resistance and sprint cycling training may not negatively or positively affect cardiometabolic risk factors in masters road cyclists. Finally, manuscript 5 entitled "Effects of concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters road cyclists” (submitted for review to the *Journal of Strength and Conditioning Research*) builds on the findings described in the review manuscripts 1 and 2. The study investigated the effects of a 12-week concurrent resistance and sprint cycling training program on lean mass, muscular strength and power, and sprint cycling performance in male masters road cyclists. The data suggests that 12-weeks of concurrent resistance and sprint cycling training significantly increases lower limb lean mass and sprint cycling performance in masters road cyclists.

Taken together, the findings presented in the above five papers make a significant and original contribution to sport science related to masters sport generally and competitive masters cyclists specifically. The findings may be used to implement a resistance and conditioning program aimed at improving lower limb lean mass and sprint cycling performance in masters road cyclists. Moreover, the results suggest the implementation of concurrent sprint and resistance training in masters endurance athletes from other sports may not only enhance sprint performance, but will not negatively affect cardiometabolic risk factors.

Certificate of Authorship and Originality of Thesis

The work contained in this thesis has not been previously submitted either in whole or in part for a degree at CQUniversity or any other tertiary institution. To the best of my knowledge and belief, the material presented in this thesis is original except where due reference is made in text.

Signed:

[redacted]

Date: 20th June 2016

Copyright Statement

Signed:

[redacted]

Date: 20th June 2016

Acknowledgements

The last 4 years has been an incredible journey for me, and I am very thankful for the experiences and people I have met along the way. There is no doubt that this thesis would not have eventuated if it wasn't for the work and commitment of a number of individuals who have played a part in this PhD. Whilst it is quite difficult to fully acknowledge the help and involvement of all the individuals who I have crossed paths with in this journey, I am certain to miss some and for that I apologise.

Firstly, and without doubt, I must thank all of the masters athletes in Rockhampton and Bundaberg for their involvement in these studies. Juggling work, family and exercise training commitments is difficult at the best of times, however to throw out the challenge of committing to 10-weeks of additional track cycling and resistance training on-top of these existing work/life commitments takes your participation to a new level! What can I say, other than these studies would not have been possible without you. In particular I would like to personally thank Peter Kane (the president of *Cycle for Life*, Rockhampton) and Joe Adair (the president of the *Rockhampton Cycling Club*) for helping me recruit the Rockhampton participants and arrange the use of the cycling velodrome. In Bundaberg, I must acknowledge and thank all of the masters cyclists who participated in this study. Specifically, I would like to thank Melinda Allen who week after week, attended, organised and recorded each track cycling training session. I hope the data and conclusions gained from this research will play an important role for your cycling programs in the future.

In addition, I would like to thank Jerome Villegas, the mastermind of our track-cycling program that we used in these studies. Without Jerome's input and training program we may well be still trying to find a suitable track cycling program for our masters cyclists. It is not easy to find training information on track cycling. In Australia, as I have learnt, it appears the secrets of track-cycling are very closely guarded by the respective track cycling organisations and coaches. I am also very thankful to you Jerome for making yourself available to come to Rockhampton and Bundaberg to personally attend and coach a track-cycling session. I know the participants, as I was, were very impressed with your knowledge and coaching ability.

I have been given a huge amount of guidance, support and at times, counselling from my research supervisors Peter Reaburn and Marko Korhonen over the last four years. Amongst my best memories of my PhD journey are all the times you Peter have patiently sent me back draft copies of my manuscripts and other writings, guiding me through the process; without using words that may have crushed my confidence (despite the fact that from the beginning, my writing can only be described as scrawl). I am not a natural writer, and I have no doubt that without you as a supervisor Peter Reaburn, I would not be here today, about to submit a PhD thesis. There are no words that can describe how lucky I feel to have found you.

Marko, I cannot begin to thank you enough for your vast wisdom on all things related to masters athletes. You too have been very patient with my, at times, impatient requests to have draft copies returned and I understand you have done this during a difficult time in your life. For that I cannot thank you enough.

There is also a very important individual I would like to thank, who has been encouraging me from the very beginning. That individual is Ken Smith; Ken you have volunteered your time to proof read my documents time and time again. Ken, I am very thankful to you for all of the support you have also given along these last 7 or 8 years I have known you.

Finally, the biggest acknowledgement I must provide is to my wife – Lally Del Vecchio. It was you that, without hesitation, agreed to give up a job, lifestyle and friends you loved, and move our four children from Sydney to Rockhampton to allow me this opportunity to achieve a dream. Your unwavering support throughout this last four years is the only reason that I have made it to this point today. This is as much your achievement as it is mine.

Finally, I would like to acknowledge CQUniversity and the Australian Government for providing an RTS supported position.

Declaration

I declare that this thesis is my own composition, all sources have been acknowledged and my contributions are clearly identified in the thesis. For any work in the thesis that has been co-published with other authors, I have permission of all co-authors to include this work in my thesis.

[redacted]

Luke Del Vecchio

PhD Candidate

Table of Contents

List of Tables

List of Figures

List of Abbreviations

1RM	1 Repetition Maximum
30WT	30 second Wingate Test
CE	Cycling Economy
CER	Concurrent Endurance and Resistance Training
CI	Confidence Intervals
CMJ	Countermovement Jump
CSA	Cross Sectional Area
CV percent	Coefficient of Variation Expressed as a Percentage
CV	Coefficient of Variation
DBP	Diastolic Blood Pressure
FBG	Fasting Blood Glucose
FLY SESSION	All sprints completed from a flying start
HPT	Peak Isometric Torque of Hamstrings
ICC	Intraclass Correlation Coefficient
IHSMF	Isometric Half Squat Maximal Force
JH	Jump Height
KE	Knee Extension
LLLM	Lower Limb Lean Mass
LLM	Lower Limb Lean Mass
MAP	Maximal Aerobic Power
MVC	Maximum Voluntary Contraction
PCRFD	Peak Concentric Rate of Force Development
PF BM^{-1}	Peak Force Body Mass
PF	Peak Force
PT	Peak Torque
PP BM^{-1}	Peak Power Body Mass
PP	Peak Power
QPT	Peak Isometric Torque of Quadriceps
RE	Running Economy
RM	Repetition Maximum
RPM	Revolutions per minute

RT	Resistance Training
SBP	Systolic Blood Pressure
SJ	Squat Jump
ST	Sprint Time
SV	Sprint Velocity
TC	Thigh Circumference
T-C	Total Cholesterol
TFM	Trunk Fat Mass
TEM	Technical Error of Measurement
TG	Triglycerides
TMS	Trained Masters Sprinters
Tmean	Mean Torque Development
TMEC	Trained Masters Endurance Cyclists
TYEC	Trained Younger Endurance Cyclists
TMER	Trained Masters Endurance Runners
TT	Flying 200 Meter Time Trial Performance
TW	Total 30 second Work
$VO_{2\ peak}$	Peak Aerobic Power
WBLM	Whole Body Lean Mass

Publications Arising From Thesis

This thesis contains published work that has been co-authored. The bibliographical details of the work and where it appears in the thesis are outlined below. A statement for each publication that clarifies the contribution of the student to the work is also provided.

Peer-Reviewed Publications

Del Vecchio, L., Korhonen, M.T., & Reaburn, P. (2016). The effects of resistance training on sprint and endurance performance in masters athletes: a narrative review. *Journal of Fitness Research.* 5(1), 5-13. (Chapter 2).

Del Vecchio, L., Villegas, J., Borges, N., & Reaburn P. (2016). Concurrent resistance training and flying 200-meter time trial program for a masters track cyclists. *Strength and Conditioning Journal*, In Press. (Chapter 3)

Del Vecchio, L. Borges, N., Reaburn, P., & Korhonen, M.T. (2016). Reliability of squat jump and countermovement jump performance in masters athletes. *La Prensa Medica Argentina*. 102(2), 1-5. (Chapter 4)

Del Vecchio, L., Reaburn, P., Trapp, G., & Korhonen, M.T. (2016). Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists, *Journal of Exercise Rehabilitation*. In Review. (Chapter 5)

Del Vecchio, L., Stanton R., Reaburn, P., Macgregor, C., Meerkin, J., & Korhonen, M.T. (2016). Effects of concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters road cyclists, *Journal of Strength and Conditioning Research*. In Review. (Chapter 6).

Conference Presentations

Macgregor, C., Del Vecchio, L., Meerkin, J., & Reaburn, P. (2015, November 1-4). *A pilot study examining the effect of 12 weeks of resistance and sprint cycle training on bone mineral content in veteran endurance cyclists*. Poster presented at the Australian and New Zealand Bone and Mineral Society 25th Annual Scientific Meeting. Hobart, Australia

Del Vecchio, L., & Reaburn P. (2016, April 14-16). *Effect of mixed methods resistance and sprint training on eccentric utilization ratio in veteran endurance cyclists*. Presented at Research to Practice, Melbourne, Australia.

Reaburn, P., Macgregor, C., Del Vecchio, L., Meerkin, J., & Korhonen, M. (2016, July 6-9). *Combined resistance and sprint training has a positive effect on bone mineral content in veteran endurance cyclists*. Presented at 21st Annual Congress of the European College of Sport Science, Vienna, Austria.

1

Introduction

1.1 Background

Masters athletes are typically older than 35 years of age and systematically train for, and compete in, organized forms of sport specifically designed for older adults (Reaburn & Dascombe, 2008). Over recent years there has been a significant increase in the number of older athletes continuing to train and compete at high performance levels within both individual sports (Lepers, Sultana, Thierry, Hausswirth, & Brisswalter, 2009; Tanaka & Seals, 2008) and multi-sport events (Hajkowicz, Cook, Wilhelmseder, & Boughen, 2013) designed for masters athletes. For example, according to the International Masters Games Association (2016) the first World Masters Games held in Toronto, Canada in 1985 had 8,305 competitors competing in 22 sports from 61 countries. In contrast, at the 2009 World Masters Games held in Sydney, Australia, there were 28,676 competitors competing in 28 sports from 95 countries. Moreover, and as a sign of the spread of masters sport across the world, the 2012 World Masters Games in Torino, Italy, had a record 107 countries attend and compete in 30 sports.

Competitive road cycling is becoming increasingly popular among masters athletes. Indeed, the number of competitive masters road cyclists registered with *Cycling Australia* has grown from 4,426 in 2013 to 10,048 in 2015 (Cycling Australia, 2016). The motives to participate in competitive masters road cycling include goal achievement, health concerns and body weight concerns (LaChausse, 2006). Collectively, the above data highlight the significant growth in masters sport participation across the world and within Australia, particularly within the sport of cycling.

1.2 Effect of age on sprint performance in masters athletes

The aging process challenges the continued ability to perform in both vigorous physical activity and competitive sports (Stiefel, Knechtle, & Lepers, 2014). Previous research has shown that the most susceptible physical attributes affected by age are speed and explosive power (Gava, Kern, & Carraro, 2015; Korhonen, Mero, & Suominen, 2003). For example, Korhonen (2003) examined the effect of age on world 100 m sprint running records and reported running speed declines linearly by 6 percent per decade in men between 20 and 80 years, and in females by 7 percent per decade between 20 and 75 years. Similarly, a study by Korhonen et al. (2003) showed that running speed during maximum speed phase of the 100 m sprint declines by ~5-6 percent per decade in elite male sprinters and by 6-7 percent in female sprinters aged between 35-88 years.

In contrast, few studies have examined the age-related decline in sprint cycling performance. Historically, Martin, Farrar, Wagner, and Spirduso (2000) reported that maximal cycling sprint power measured during 3-4 seconds of all-out effort, using inertial load cycle ergometry declined by 7.5 percent per decade in competitive male cyclists aged 30-70 years. In addition, a recent analysis of the flying 200 m track cycling world records of masters athletes aged 30-75 years showed sprint performance declines by 2.8 percent and 11.2 percent per decade in males and females, respectively (Del Vecchio, Korhonen, & Reaburn, 2016).

The age-related decline in sprint performance across a range of sports is multi-factorial, with the precise mechanisms responsible for the declining performances remaining speculative. The current research evidence suggests that age-related morphological and neuromuscular changes both contribute to the age-related reduction in sprint performance observed in masters athletes. Specifically, age-related morphological changes include declines in muscle mass (Korhonen et al., 2006; Martin et al., 2000) and reduction in the size of fast-contracting and powerful type II muscle fibres (Zampieri et al., 2015). Age-related changes in neuromuscular function include a decrease in maximal strength, muscular power and the rate of force development (Korhonen, 2009; Korhonen et al., 2006). In addition to the morphological changes, there may be a preferential loss of the motor units which innervate fast twitch muscle fibres (Drey et al., 2016) and a reduction in neural activation capacity (Brisswalter & Nosaka, 2013; Leong, Kamen, Patten, & Burke, 1999). Taken together, these data suggest both morphological and neuromuscular changes contribute to the decline in sprint performance observed in masters athletes. However, it remains unknown if resistance training can attenuate these morphological and neuromuscular changes which affect sprint performance in masters athletes in general and masters road cyclists specifically.

1.3 Resistance training improves sprint performance in masters sprint runners

Resistance training in both previously sedentary older individuals (Churchward-Venne et al., 2015; Reid et al., 2015; Vechin et al., 2015) and masters athletes (Cristea, 2008; Reaburn, Logan, & Mackinnon, 1994) has been shown to elicit adaptations in both morphology and neuromuscular function that may counteract the age-related changes in sprint performance in aging athletes. For example, in masters sprint runners, Cristea (2008) reported significant 20 percent increases in type IIA muscle fibre size and neural activation of the agonist leg extensor muscles during a squat jump in response to a 20-week concurrent sprint, resistance and power training program in male masters sprint runners aged 66.0 ± 3.0 years. A previous study by Reaburn et al. (1994) reported significant 3.3 percent increases in thigh circumference along with 14.4 percent and 9.4 percent increases in hamstring and quadriceps peak torques, respectively, in response to an 8-week concurrent sprint and resistance training program in masters sprint runners aged 54.7 ± 5.5 years.

The need for masters athletes to engage in concurrent resistance and sprint training is based on three physiological mechanisms. Firstly, hypertrophy training offsets the age-related decrease in muscle mass and muscle fibre size commonly observed in both normal aging populations (Leenders et al., 2013; Nilwik et al., 2013) and masters athletes (Cristea et al., 2008a; Korhonen et al., 2006; Reaburn et al., 1994). Secondly, high intensity resistance training stimulates type II motor units, maintaining innervation and size of fast twitch muscle fibres critical for speed and power performance (Aagaard, Suetta, Caserotti, Magnusson, & Kjær, 2010; Newton et al., 2002). Finally, explosive resistance training exercises and plyometrics commonly used in resistance training programs both maximize fast and coordinated neural activation of major muscle groups needed for muscular speed and power development (Cristea et al., 2008a; Häkkinen et al., 1998). While concurrent resistance and sprint cycling training is common among elite young road cyclists (Rønnestad, Hansen, & Raastad, 2010), it is currently unclear whether concurrent resistance and sprint cycling training is effective in masters road cyclists for either health or performance benefits.

1.4 Cardiometabolic risk factors in masters athletes

Cardiometabolic syndrome is a clustering of interrelated risk factors that promote the development of atherosclerotic vascular disease and type 2 diabetes (Phillips, Mahmoud, Brown, & Haus, 2015). The risk of cardiometabolic syndrome increases with age (Kim & Choi, 2015). The specific factors that appear to cause increased risk for cardiometabolic disease include obesity, hyperglycaemia, hypertension, insulin resistance, dyslipidaemia, and low muscle mass (Kim & Choi, 2015).

It is well known that increasing physical activity levels can reduce cardiometabolic risk. For example, in previously sedentary older adults low-moderate intensity endurance training reduces cardiometabolic risk by increasing high density lipoprotein (HDL) cholesterol levels (Park et al., 2015; Parto, Lavie, Swift, & Sui, 2015), decreasing triglycerides (Park et al., 2015; Parto et al., 2015) and decreasing resting blood pressure (Bruseghini et al., 2015). Previous research has shown that masters athletes exhibit positive health benefits of competitive sport through a reduction in cardiometabolic risk. In masters athletes these benefits include higher HDL-cholesterol levels (Batista & Soares, 2013), lower triglycerides (Lynch, Ryan, Evans, Katzel, & Goldberg, 2007), lower resting blood pressure (Dey, Ghosh, Debray, & Chatterjee, 2002), and improved body composition (Kusy, Zieliński, & Pilaczyńska-Szcześniak, 2013a).

It is well known that endurance training into older age produces several positive health effects that lower the risk for cardiometabolic disease (Buyukyazi, 2005; Hayes et al., 2013; Mikkelsen et al., 2013a; Randers et al., 2014). For example, when compared to inactive, age-matched controls, endurance-trained masters athletes have lower blood pressure (Hayes et al., 2013; Randers et al., 2014), higher HDL-cholesterol and lower triglyceride levels (Buyukyazi, 2005; Mikkelsen et al., 2013a), improved glucose tolerance (Lanza et al., 2008; Mikkelsen et al., 2013a) and improved body composition (Hayes et al., 2013). Collectively, these data suggest endurance training into older age reduces the risk of cardiometabolic disease. However, a limited number of previous studies have investigated the effects of concurrent resistance and sprint training on cardiometabolic risk factors in masters road cyclists.

Speed- and power-based sports such as sprint cycling require a strong emphasis on resistance and sprint training (Young, 2006). In addition, recent research suggests that high intensity sprint training may safely and effectively promote cardiometabolic health in both clinical and healthy older populations (Bell, Séguin, Parise, Baker, & Phillips, 2015;

Kessler, Sisson, & Short, 2012; Nederveen et al., 2015). Moreover, in speed and power-trained masters athletes (track and field sprinters, throwers and jumpers), previous research has shown that, when compared to age-matched inactive controls, these speed- and power-trained masters athletes display lower rates of hypertension (Kettunen, Kujala, Kaprio, & Sarna, 2006), lower blood lipids (Kusy & Zielinski, 2015a; Marti, Knobloch, Riesen, & Howald, 1991), improved body composition (Nowak et al., 2010) and insulin sensitivity (Kusy, Zieliński, & Pilaczyńska-Szcześniak, 2013).

In addition to the cardiometabolic benefits of high intensity sprint training, a number of previous studies have also shown that resistance training alone may have positive effects on cardiometabolic risk factors in older adults (Drenowatz et al., 2015; Scanlon et al., 2014; Thomas et al., 2005). Specifically, older adults who regularly undergo resistance training have been shown to exhibit lower fasting glucose, total cholesterol and body fat (Drenowatz et al., 2015), increased muscle mass (Scanlon et al., 2014) and improved insulin sensitivity (Thomas et al., 2005) compared to inactive age-matched controls. However, no studies to date have investigated the effects of resistance training on cardiometabolic risk factors in masters athletes. Moreover, no studies to date have investigated the combined effects of resistance and sprint training on cardiometabolic risk factors in masters road cyclists who are already endurance-trained and thus may already have a positive cardiometabolic risk profile.

In summary, previous research suggests that participating in organized sport as a masters athlete may reduce cardiometabolic risk factors by maintaining insulin sensitivity, resting blood pressure and improving blood lipid profiles as a result of increased HDL cholesterol and decreased triglyceride levels. However, no research to date has examined the effects of concurrent resistance and sprint cycle training on cardiometabolic risk factors in masters athletes who are already endurance-trained.

1.5 Statement of the research problem

The well established guidelines for developing speed in younger athletes may not necessarily apply to masters athletes due to age-related changes in the neuromuscular system of older athletes. To date, the majority of research into age-related declines in sprint performance in masters athletes have relied on studies examining track sprint runners with no research to date examining the effect of concurrent resistance and sprint cycling training on strength, power and speed in masters road cyclists. Moreover, the effect of concurrent resistance and sprint training on cardiometabolic risk factors has yet to be investigated in masters endurance athletes.

Examining the effect of concurrent resistance and sprint cycling training on sprint performance, and physiological, morphological and neuromuscular characteristics in aging masters athletes may not only demonstrate the importance of such training for enhancing sprint cycling performance but also provide valuable information about the potential health benefits of such training in both masters athletes and healthy older, non-athletic adults. Theoretically, performance may be improved through an increase in muscle mass, increased muscle strength and power, and improvements in neural activation and thus the prevention of denervation and loss of motor units commonly observed in older individuals. Moreover, concurrent resistance and sprint training may lead to an improvement in body composition, a decrease in fasting blood glucose levels, an increase in total cholesterol levels, and a reduction in triglyceride levels and resting blood pressure in endurance-trained masters athletes. Collectively, these positive morphological, neurological and cardiometabolic changes may improve sprint cycling performance while also reducing cardiometabolic risk factors in both masters athletes and recreationally active older adults.

1.6 Thesis aims and hypotheses

The overall aim of the present thesis is to examine the performance and health benefits of concurrent resistance and sprint cycling training in well-trained masters road cyclists. Outlined below are the specific titles, aims and/or hypotheses for each of the papers included within the current thesis:

Chapter 2 The effects of resistance training on sprint and endurance performance in masters athletes:

Aim: To review the effects of resistance training on sprint and endurance performance and its physiological determinants in masters athletes.

Chapter 3 Development of a concurrent resistance and sprint cycling program.

Aim: To develop a concurrent resistance and sprint cycling training program that will enhance sprint cycling performance in masters road cyclists.

Chapter 4 Reliability of explosive muscular power testing in masters athletes.

Aim: To assess the test-retest reliability of squat jump and countermovement jump power measures in masters athletes.

Hypothesis: Masters athletes will display greater variability in squat jump and countermovement jump peak power than younger athletes. However, both SJ and CMJ peak power will meet acceptable test-retest reliability standards.

Chapter 5 Health benefits of concurrent resistance and sprint cycling training.

Aim: To examine the effect of a concurrent resistance and sprint cycling training program on cardiometabolic risk factors in masters road cyclists.

Hypothesis: 12-weeks of concurrent resistance and sprint cycling training will improve body composition without negatively impacting cardiometabolic risk factors in masters road cyclists.

Chapter 6: Performance benefits of concurrent resistance and sprint cycling training.

Aim: To examine the effect of a 12-week concurrent resistance and sprint cycling training program on lean mass, strength and power and sprint cycling performance in masters road cyclists.

Hypothesis: 12-weeks of concurrent resistance and sprint-cycling training will significantly increase lean mass, muscular strength and power, and sprint cycling performance of masters road cyclists.

1.7 Contributions of this research

As participation in competitive masters cycling increases worldwide there will be an increasing demand for scientific research to optimise training strategies for maintaining muscle mass, increasing strength and increasing explosive muscular power, and developing both sprint and endurance cycling performance in masters cyclists. A concurrent resistance and sprint cycling training program specifically designed to meet the unique needs of the masters athlete may provide the necessary stimulus to achieve improvement in sprint cycling speed. Additionally, a concurrent resistance and sprint cycling training program may also reduce cardiometabolic risk factors by improving lipid profiles, reducing blood pressure and improving body composition in older cyclists.

The findings from the present research may provide valuable knowledge and information to exercise physiologists, sport scientists, coaches, strength and conditioning specialists, and other medical and health professionals regarding the potential health benefits of concurrent resistance and sprint cycling for masters athletes. In addition, the findings from this research will also provide coaches, strength and conditioning specialists, and sport science practitioners with training guidelines for speed development in masters cyclists or masters athletes from a range of sports.

The structure of the present thesis is seven Chapters which document specific research projects. Chapter 2 of the present thesis presents a narrative review that provides a synthesis of the previous research that has examined the effects of resistance training on endurance and sprint performance in masters athletes. The narrative review was peer-reviewed and published in the *Journal of Fitness Research*. Chapter 3 will then focus on the development and implementation of a concurrent resistance and sprint cycling training program aimed at improving sprint cycling performance in masters road cyclists by the careful manipulation of several acute and chronic training variables. The concurrent resistance and sprint cycling training program was peer-reviewed and published in the *Strength and Conditioning Journal*.

The valid and reliable assessments of athletic performance is critical. Few studies have investigated the reliability of measures of explosive muscular power in masters athletes. Thus, Chapter 4 describes a study examining the day-to-day variation in a battery of commonly-used tests and measures of explosive muscular power. The study was published in a peer-reviewed journal, *La Prensa Medica Argentina.* Chapters 5 and 6 of the thesis describe the effects of 12-weeks of concurrent resistance and sprint cycle training on cardiometabolic risk factors (Chapter 5) and sprint cycling performance (Chapter 6) in well-trained masters road cyclists. Finally, Chapter 7 summarises the findings of the above series of papers and related studies, presents the overall conclusions, suggests a number of implications of the research findings, and provides directions for future research.

1.8 References

Aagaard, P., Suetta, C., Caserotti, P., Magnusson, S. P., & Kjær, M. (2010). Role of the nervous system in sarcopenia and muscle atrophy with aging: Strength training as a countermeasure. *Scandinavian Journal of Medicine & Science in Sports, 20*(1), 49-64.

Batista, C., & Soares, J. M. (2013). Are former elite athletes more protected against metabolic syndrome? *Journal of cardiology, 61*(6), 440-445.

Bell, K. E., Séguin, C., Parise, G., Baker, S. K., & Phillips, S. M. (2015). Day-to-day changes in muscle protein synthesis in recovery from resistance, aerobic, and high-intensity interval exercise in older men. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 70*(8), 1024-1029.

Brisswalter, J., & Nosaka, K. (2013). Neuromuscular factors associated with decline in long-distance running performance in master athletes. *Sports Medicine, 43*(1), 51-63.

Bruseghini, P., Calabria, E., Tam, E., Milanese, C., Oliboni, E., Pezzato, A., Mucelli, R. P. (2015). Effects of eight weeks of aerobic interval training and of isoinertial resistance training on risk factors of cardiometabolic diseases and exercise capacity in healthy elderly subjects. *Oncotarget, 6*(19), 16998-7015.

Buyukyazi, G. (2005). Differences in blood lipids and apolipoproteins between master athletes, recreational athletes and sedentary men. *Journal of Sports Medicine and Physical Fitness, 45*(1), 112.

Churchward-Venne, T. A., Tieland, M., Verdijk, L. B., Leenders, M., Dirks, M. L., de Groot, L. C., & van Loon, L. J. (2015). There are no nonresponders to resistance-type exercise training in older men and women. *Journal of the American Medical Directors Association, 16*(5), 400-411.

Cristea, A. (2008). *Effects of ageing and physical activity on regulation of muscle contraction*. (Doctoral Thesis). Acta Universitatis Upsaliensis, Upsaliensis.

Cristea, A., Korhonen, M., Häkkinen, K., Mero, A., Alén, M., Sipilä, S., Larsson, L. (2008). Effects of combined strength and sprint training on regulation of muscle contraction at the whole muscle and single fibre levels in elite master sprinters. *Acta Physiologica, 193*(3), 275-289.

Cycling Australia. (2016). Cycling Australia annual reports. Retrived from: http://www.cycling.org.au/Home/About-CA/Annual-Reports

Del Vecchio, L., Korhonen, M. T., & Reaburn, P. (2016). The effects of resistance training on sprint running and sprint cycling performance in masters athletes: A narrative review. *Journal of Fitness Research,* 5(1), 5-13.

Dey, S. K., Ghosh, C., Debray, P., & Chatterjee, M. (2002). Coronary artery disease risk factors & their association with physical activity in older athletes. *Journal of Cardiovascular Risk, 9*(6), 383-392.

Drenowatz, C., Sui, X., Fritz, S., Lavie, C. J., Beattie, P. F., Church, T. S., & Blair, S. N. (2015). The association between resistance exercise and cardiovascular disease risk in women. *Journal of Science and Medicine in Sport, 18*(6), 632-636.

Drey, M., Sieber, C. C., Degens, H., McPhee, J., Korhonen, M. T., Müller, K., Rittweger, J. (2016). Relation between muscle mass, motor units and type of training in master athletes. *Clinical Physiology and Functional Imaging, 36*(1), 70-76.

Gava, P., Kern, H., & Carraro, U. (2015). Age-associated power decline from running, jumping, and throwing male masters world records. *Experimental Aging Research, 41*(2), 115-135.

Hagerman, F., Walsh, S., Staron, R., Hikida, R., Gilders, R., Murrary, T., & Ragg, K. (2000). Effects of high-intensity resistance training on untrained older men. I. Strength, cardiovascular, and metabolic responses. *The Journals of Gerontolology Series: A, Biological Sciences and Medical Sciences, 55*(7), B336-B346.

Hajkowicz, S., Cook, H., Wilhelmseder, L., & Boughen, N. (2013). The future of Hustralian sport: Megatrends shaping the sports sector over coming decades. A consultancy report for the Hustralian sports commission: CSIRO, Australia.

Häkkinen, K., Kallinen, M., Izquierdo, M., Jokelainen, K., Lassila, H., Mälkiä, E., Alen, M. (1998). Changes in agonist-antagonist emg, muscle csa, and force during strength training in middle-aged and older people. *Journal of Applied Physiology, 84*(4), 1341-1349.

Hayes, L. D., Grace, F. M., Sculthorpe, N., Herbert, P., Kilduff, L. P., & Baker, J. S. (2013). Does chronic exercise attenuate age-related physiological decline in males? *Research in Sports Medicine, 21*(4), 343-354.

Hernelahti, M., Kujala, U. M., Kaprio, J., Karjalainen, J., & Sarna, S. (1998). Hypertension in master endurance athletes. *Journal of Hypertension, 16*(11), 1573-1577.

International Masters Games Association. (2016). Previous masters events. Retrieved from: https://imga.ch/en/events/#previousevents

Kessler, H. S., Sisson, S. B., & Short, K. R. (2012). The potential for high-intensity interval training to reduce cardiometabolic disease risk. *Sports Medicine, 42*(6), 489-509.

Kettunen, J. A., Kujala, U. M., Kaprio, J., & Sarna, S. (2006). Health of master track and field athletes: A 16-year follow-up study. *Clinical Journal of Sport Medicine, 16*(2), 142-148.

Kim, T. N., & Choi, K. M. (2015). The implications of sarcopenia and sarcopenic obesity on cardiometabolic disease. *Journal of Cellular Biochemistry, 116*(7), 1171-1178.

Korhonen, M. T., Cristea, A., Alén, M., Häkkinen, K., Sipilä, S., Mero, A., Suominen, H. (2006). Aging, muscle fiber type, and contractile function in sprint-trained athletes. *Journal of Applied Physiology, 101*(3), 906-917.

Korhonen, M. T., Mero, A., & Suominen, H. (2003). Age-related differences in 100-m sprint performance in male and female master runners. *Medicine and Science in Sports and Exercise, 35*(8), 1419-1428.

Kusy, K., & Zielinski, J. (2015). Sprinters versus long-distance runners: How to grow old healthy. *Exercise and Sport Sciences Reviews, 43*(1), 57-64.

Kusy, K., Zieliński, J., & Pilaczyńska-Szcześniak, Ł. (2013). Insulin sensitivity and β-cell function estimated by homa2 model in sprint-trained athletes aged 20− 90 years vs endurance runners and untrained participants. *Journal of Sport Sciences, 31*(15), 1656-1664.

LaChausse, R. G. (2006). Motives of competitive and non-competitive cyclists. *Journal of Sport Behavior, 29*(4), 304.

Lanza, I. R., Short, D. K., Short, K. R., Raghavakaimal, S., Basu, R., Joyner, M. J., Nair, K. S. (2008). Endurance exercise as a countermeasure for aging. *Diabetes, 57*(11), 2933-2942.

Leenders, M., Verdijk, L. B., van der Hoeven, L., van Kranenburg, J., Nilwik, R., & van Loon, L. J. (2013). Elderly men and women benefit equally from prolonged resistance-type exercise training. *The Journals of Gerontolology Series: A, Biological Sciences and Medical Sciences, 68*(7), 769-779.

Leong, B., Kamen, G., Patten, C., & Burke, J. R. (1999). Maximal motor unit discharge rates in the quadriceps muscles of older weight lifters. *Medicine and Science in Sports and Exercise, 31*(11), 1638-1644.

Lepers, R., Sultana, F., Thierry, B., Hausswirth, C., & Brisswalter, J. (2009). Age-related changes in triathlon performance. *International Journal of Sports Medicine, 30*, 1-6.

Louis, J., Hausswirth, C., Easthope, C., & Brisswalter, J. (2012). Strength training improves cycling efficiency in master endurance athletes. *European Journal of Applied Physiology, 112*(2), 631-640.

Lynch, N. A., Ryan, A. S., Evans, J., Katzel, L. I., & Goldberg, A. P. (2007). Older elite football players have reduced cardiac and osteoporosis risk factors. *Medicine and Science in Sports and Exercise, 39*(7), 1124-1130.

Marti, B., Knobloch, M., Riesen, W. F., & Howald, H. (1991). Fifteen-year changes in exercise, aerobic power, abdominal fat, and serum lipids in runners and controls. *Medicine and Science in Sports and Exercise*, *23*(1), 115-122.

Martin, J., Farrar, R., Wagner, B., & Spirduso, W. (2000). Maximal power across the lifespan. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55*(6), M311-M316.

Mengelkoch, L. J., Pollock, M. L., Limacher, M. C., Graves, J. E., Shireman, R. B., Riley, W. J., Leon, A. S. (1997). Effects of age, physical training, and physical fitness on coronary heart disease risk factors in older track athletes at twenty-year follow-up. *Journal of the American Geriatrics Society, 45*(12), 1446-1453.

Mikkelsen, U., Couppe, C., Karlsen, A., Grosset, J., Schjerling, P., Mackey, A., Kjær, M. (2013). Life-long endurance exercise in humans: circulating levels of inflammatory markers and leg muscle size. *Mechanisms of Ageing and Development, 134*(11), 531-540.

Nederveen, J., Joanisse, S., Séguin, C., Bell, K., Baker, S., Phillips, S., & Parise, G. (2015). The effect of exercise mode on the acute response of satellite cells in old men. *Acta Physiologica, 215*(4), 177-190.

Newton, R. U., Hakkinen, K., Hakkinen, A., McCormick, M., Volek, J., & Kraemer, W. J. (2002). Mixed-methods resistance training increases power and strength of young and older men. *Medicine and Science in Sports and Exercise, 34*(8), 1367-1375.

Nilwik, R., Snijders, T., Leenders, M., Groen, B. B., van Kranenburg, J., Verdijk, L. B., & van Loon, L. J. (2013). The decline in skeletal muscle mass with aging is mainly attributed to a reduction in type ii muscle fiber size. *Experimental Gerontology, 48*(5), 492-498.

Nowak, A., Straburzyńska-Lupa, A., Kusy, K., Zieliński, J., Felsenberg, D., Rittweger, J., Pilaczyńska-Szcześniak, Ł. (2010). Bone mineral density and bone turnover in male masters athletes aged 40–64. *The Aging Male, 13*(2), 133-141.

Park, Y.-M. M., Sui, X., Liu, J., Zhou, H., Kokkinos, P. F., Lavie, C. J., Blair, S. N. (2015). The effect of cardiorespiratory fitness on age-related lipids and lipoproteins. *Journal of the American College of Cardiology, 65*(19), 2091-2100.

Parto, P., Lavie, C. J., Swift, D., & Sui, X. (2015). The role of cardiorespiratory fitness on plasma lipid levels. *Expert Review of Cardiovascular Therapy, 13*(11), 1177-1183.

Phillips, S. A., Mahmoud, A. M., Brown, M. D., & Haus, J. M. (2015). Exercise interventions and peripheral arterial function: Implications for cardio-metabolic disease. *Progress in Cardiovascular Diseases, 57*(5), 521-534.

Piacentini, M. F., De Ioannon, G., Comotto, S., Spedicato, A., Vernillo, G., & La Torre, A. (2013). Concurrent strength and endurance training effects on running economy in master endurance runners. *The Journal of Strength & Conditioning Research, 27*(8), 2295-2303.

Randers, M. B., Andersen, J. L., Petersen, J., Sundstrup, E., Jakobsen, M. D., Bangsbo, J., Krustrup, P. (2014). Exercise performance and cardiovascular health variables in 70-year-old male soccer players compared to endurance-trained, strength-trained and untrained age-matched men. *Journal of Sports Sciences, 32*(13), 1300-1308.

Reaburn, P., & Dascombe, B. (2008). Endurance performance in masters athletes. *European Review of Aging and Physical Activity*, *5*(1), 31-42.

Reaburn, P., Logan, P., & Mackinnon, L. (1994). The effect of hypertrophy resistance training on anaerobic work capacity in veteran sprint runners. *Australian Sports Commission*. Retrieved from: https://www.clearinghouseforsport.gov.au/__data/assets/pdf_file/0006/198375/RP1996summary.pdf

Reid, K. F., Martin, K. I., Doros, G., Clark, D. J., Hau, C., Patten, C., Fielding, R. A. (2015). Comparative effects of light or heavy resistance power training for improving lower extremity power and physical performance in mobility-limited older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *70*(3), 372-378.

Rønnestad, B. R., Hansen, E. A., & Raastad, T. (2010). Effect of heavy strength training on thigh muscle cross-sectional area, performance determinants, and performance in well-trained cyclists. *European Journal of Applied Physiology, 108*(5), 965-975.

Scanlon, T. C., Fragala, M. S., Stout, J. R., Emerson, N. S., Beyer, K. S., Oliveira, L. P., & Hoffman, J. R. (2014). Muscle architecture and strength: Adaptations to short-term resistance training in older adults. *Muscle & Nerve, 49*(4), 584-592.

Stiefel, M., Knechtle, B., & Lepers, R. (2014). Master triathletes have not reached limits in their ironman triathlon performance. *Scandinavian Journal of Medicine & Science in Sports*, *24*(1), 89-97.

Suominen, H. (2011). Ageing and maximal physical performance. *European Review of Aging and Physical Activity, 8*(1), 37-42.

Tanaka, H., & Seals, D. R. (2008). Endurance exercise performance in masters athletes: Age-associated changes and underlying physiological mechanisms. *The Journal of Physiology, 586*(1), 55-63.

Thomas, G. N., Hong, A. W., Tomlinson, B., Lau, E., Lam, C. W., Sanderson, J. E., & Woo, J. (2005). Effects of tai chi and resistance training on cardiovascular risk factors in elderly chinese subjects: A 12-month longitudinal, randomized, controlled intervention study. *Clinical Endocrinology, 63*(6), 663-669.

Vechin, F. C., Libardi, C. A., Conceição, M. S., Damas, F. R., Lixandrão, M. E., Berton, R. P., Chacon-Mikahil, M. P. T. (2015). Comparisons between low-intensity resistance training with blood flow restriction and high-intensity resistance training on quadriceps muscle mass and strength in elderly. *The Journal of Strength & Conditioning Research, 29*(4), 1071-1076.

Young, W. B. (2006). Transfer of strength and power training to sports performance. *International Journal of Sports Physiology and Performance, 1*(2), 74.

Zampieri, S., Pietrangelo, L., Loefler, S., Fruhmann, H., Vogelauer, M., Burggraf, S., Sedliak, M. (2015). Lifelong physical exercise delays age-associated skeletal muscle decline. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *70*(2), 163-173.

2

Manuscript 1 – Literature review:

The Effects of Resistance Training on Sprint and Endurance Performance in Masters Athletes.

This chapter is presented with the text formatting and referencing styles required by the peer-reviewed *Journal of Fitness Research* in which the paper was published.

Declaration of Co-Authorship and Contribution

Title of Paper	The effects of Resistance Training on Sprint and Endurance Performance in Masters Athletes: a narrative review
Full bibliographic reference for Journal/Book in which the Paper appears	Del Vecchio, L., Korhonen, M.T., Reaburn, P. (2016). The effects of resistance training on sprint and endurance performance in masters athletes: a narrative review. *Journal of Fitness Research.* 5(1), 5-13
Status	Published

Nature of Candidate's Contribution

Luke Del Vecchio was responsible for each data base search, the review of all abstracts, and articles, drafted the manuscript in full, edited the manuscript based on co-author feedback, submitted the manuscript, and responded to reviewer comments.

Nature of Co-Authors' Contributions

Peter Reaburn and Marko Korhonen reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Please Note the reference format in the following paper is "as per the journals required referencing format".

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Publication of Research Higher Degree Work for Inclusion in the Thesis Procedures

Signature:

Date: 20th June 2016

The effects of Resistance Training on Sprint and Endurance Performance in Masters Athletes: a narrative review

2.1 Abstract

Participation of masters athletes (>35 years) in sprint running (100-400 m) and sprint track cycling (200 m, team sprint, 1-km) has increased significantly over recent decades. With aging, sprint and endurance performance gradually declines. The present review focuses upon the effects of resistance training on sprint and endurance performance and its physiological determinants in masters athletes. The available research demonstrates resistance training interventions in masters athletes can lead to beneficial adaptations in both sprint and endurance athletes. With inclusion of heavy strength training exercises in sprinters' training regimen, increases in muscle mass, size of fast twitch fibers and rapid neural activation capacity, along with improvements in maximal, explosive and sprint force production have been observed. In endurance athletes, strength training has been shown to lead to increased maximal and explosive muscle strength levels. The actual event-specific performance changes are typically smaller, but significant ($p<0.05$), with 2-4% reductions in sprint running times and 3-6% improvements in endurance cycling and running economy. Taken together, these limited data suggest resistance training programs produce positive effects on physiological determinants of sprint and endurance performance that are manifested in enhanced sport performance capacity in masters athletes. Further research on these issues is needed to design and deliver optimal training programs to aging athletes.

Key Words: veteran, older athletes, sprint running, cycling, aging, strength training, endurance performance

2.2 Introduction

Masters athletes are individuals who participate in local, national or international competitive sporting activities specifically designed for middle-aged and older adults.[1] Over recent decades there has been a significant increase in the number of masters athletes continuing to train and compete at high performance levels within both individual sports[2,3] and multi-sport events.[4] The rising popularity of masters sporting competitions can be seen by the increasing numbers of participation in the World Masters Games. For example, the first World Masters Games in Toronto in 1975 had over 8 000 competitors, while in 2009 over 28 000 athletes took part in the World Masters Games in Sydney.[5] Moreover, participation trends in masters track cycling are also increasing; in 2005, there were 292 entrants from 20 nations who took part in the Union Cycliste Internationale (UCI) track cycling masters world championships, in 2013 this number increased to 400 entrants, from 28 countries. Taken together, these data highlight the increasing participation numbers in competitive masters sporting events.

In track-cycling, the 200 m flying start is the qualifying event for sprint competition, which is considered the most explosive effort amongst high-performance track cycling events.[6] Leading international younger male track-cyclists, complete this event in 10 seconds (females in 12 seconds) with cycling cadences between 150-160 rpm [6,7] and power outputs of 18 to 22 W/kg.[6,7] Elite younger male sprint runners complete the 100 m event in 10 seconds (females in 11 seconds) with running velocities of up to 12 m/s during the maximum speed phase. Such performance requires peak power outputs that approach 18 W/kg.[7,8] Thus, both sprint cycling and sprint running performances impose high demands on maximal speed-power capacities affected by anaerobic ATP-creatine phosphate and glycolytic energy systems. Therefore, one important challenge for both researchers and strength and conditioning coaches is to find the most effective training methods that might counteract the well documented decrements in sprint and endurance performance in masters athletes

In light of these findings, it might be suggested that the inclusion of a resistance training program into sprint training programs may enhance sprint performance in aging athletes. Indeed, previous research[11-13] has demonstrated a need for masters athletes to engage in resistance training programs to improve sprint performance for three reasons. Firstly, hypertrophy resistance training may offset the age-related decrease in both muscle fiber size and number commonly observed in ageing populations.[14,15] Secondly, high-intensity resistance training stimulates fast-twitch muscle fibers and motor units.[12,16] Finally, both explosive power weight training exercises and plyometrics maximize coordinated neuromuscular recruitment and elastic behavior of the muscle-tendon complex.[11,17] The purpose of this narrative review is to examine the effects of resistance training on sprint and endurance running and cycling performance in masters athletes.

2.3 Methods

A literature search was conducted between November and December 2015 using the electronic databases of Ausport, Cochrane, Embase, Scopus, Sportdiscus and Medline. The following search terms of masters athlete OR veteran AND strength training OR resistance training were used. Studies were included in this review if they satisfied all of the following criteria: male, aged 35 years or older and described as masters athletes or veteran, who participated in a resistance training intervention (Figure 2.1). Further restrictions were applied to only include full-text peer reviewed articles, available in English language. An additional perusal of relevant reference lists was also undertaken to further ensure all relevant data has been identified.

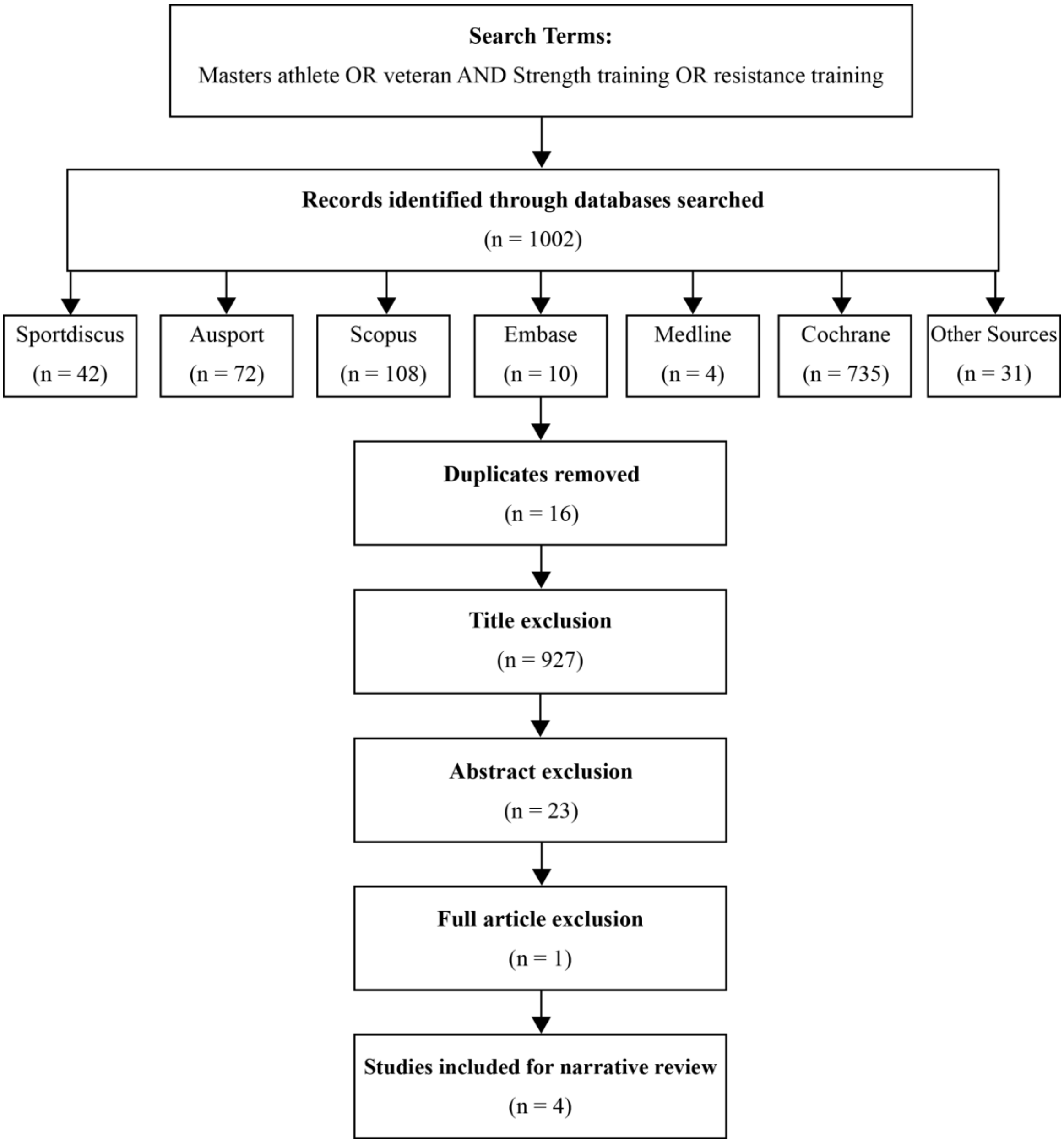

Figure 2.1. Narrative review flow chart

2.4 Results

A total of four studies met the inclusion criteria and were subsequently included in this review. Of the four articles reviewed, a total of 46 trained masters athletes (37 males and 9 females), with a mean age of 52.2 ± 8.8 years, participated in a resistance training intervention. Intervention components such as the frequency of sessions and the duration of interventions varied. Specifically, duration of interventions ranged from 3 – 20 weeks, while the frequency of interventions ranged from 2-3 sessions per week. Results suggest significant improvements ($p<0.05$) in 60 m and 100 m sprint time, running economy, cycling economy, knee extension peak torque and 1RM squat and leg press strength. Further details are provided in Table 2.1.

Table 2.1. Studies investigating the effects of resistance training on sprint and endurance performance in masters athletes

Piacentini et al. (2013)	16 TMER	MST group: 44.2 ± 3.9 years RT group: 44.8 ± 4.4 years C group: 43.2 ± 7.9 years	MST Group: 4 x M 2 x F RT Group: 3 x M 2 x F C Group: 5 x M 2 x F	6-wk CERS RT: two times per week,, 3x10, 70% 1RM, bench press, lat pulldown, seated row, cable shoulder press, triceps extension, bicep curl. ½ squat, calf press, lunges, eccentric leg extensions on leg press MST: 4 x 3-4, 85-90% 1RM, same exercises	1RM LP, CMJ, SJ, RE	Significant increase in 1RM LP and RE in the MST group only.	16.3% increase in leg press 1RM LP in MST group. 6.1% increase in RE in MST group
Louis et al. (2012).	9 TMEC 8 TYEC	51.5 ± 5.5 years 25.6 ± 5.9 years	Gender not specified.	3-wk CER RT: three times per week, 10 x 10 knee extension 70% 1RM.	KE-MVC, Tmean, CE	Significant increase in KE-MVC, Tmean and CE.	17.8% increase KE MVC in TMEC. 5.9% increase in KE MVC in TYEC. 6.9% increase in Tmean in TMEC. 3% increase in CE in TMEC.
Cristea et al (2008)	9 TMS	54.7 ± 5.5 years	males	20-wk CSR RT: two times per week, periodised sets and reps scheme. ST: two s·wk, 20-60 m track sprint training	10m SV, 60 m ST, 1RM SQ, SJ, TJ	Significant increase in SV, 60 mST, 1RM SQ, SJ and TJ performance	4% improvement in 10 m SV. 2% improvement in 60 m ST. 27% increase in 1RM SQ. 10% in SJ. 4% increase in TJ.

Reaburn and Mackinnon (1996)	12 TMS	54.7 ± 5.5 years	males	8-wk CSR RT: two times per week, 3 x 8-12RM leg extension, leg curl, leg press, half-squat. ST: 8-wk, two times per week, 100 & 300 meter track sprint training.	100 m ST, 300 m sprint time, QS MVC, HS MVC, TC	Significant improvement in 100 m sprint performance, TC, QS and HS PT	4% improvement in 100 m sprint time. 1.1% increase in QS PT and HS PT. 1% increase in TC.

TMER = Trained Masters Endurance Runners; MST = Maximum Strength Training; RT = Resistance Training, C = Control Group; 1RM = 1 Repetition Maximum; LP = Leg Press; CMJ = Countermovement Jump; SQ = Squat, SJ = Squat Jump, RE = Running Economy; ; TMEC = Trained Masters Endurance Cyclists; TYEC = Trained Younger Endurance Cyclists; CER = Concurrent Endurance and Resistance Training Program; CE = Cycling Economy, KE = Knee Extension; MVC = Maximum Voluntary Contraction; Tmean = mean torque development; TMS = Trained Masters Sprinters; CSR = Concurrent Sprint and Resistance Training Program; SV = Sprint Velocity; ST = Sprint Time; TJ = Triple Jump, QS = Quadriceps, HS = Hamstrings, PT = Peak Torque, TC = Thigh Circumference, 30WT = 30 Second Wingate Test, CSA = Cross Sectional Area, IHSMF = Isometric Half Squat Maximal Force.

2.5 Discussion

2.5.1 The effects of aging on sprint running and sprint cycling performance

This first section reviews research that has investigated the age-related decline in the energetically similar events of 100 m sprint running and 200 m sprint cycling performance.

A number of studies have investigated the decline in sprint running performance with age.[18-21] For example, Suominen (2011)[20] examined world 100 m sprint running records and reported that running speed declined quite linearly by 6% per decade in men between 20 and 80 years, and in females by 7% per decade between 20 and 75 years. After age 75-80 years, reductions in 100 m record performances become more evident. In a study conducted in European Veterans Athletics Championships, Korhonen et al. (2003)[19] observed that in 100 m finalists, maximum speed declined by 5-6% per decade in male masters sprinters and by 6-7% in female masters sprinters aged between 35-88 years. The observed decline in maximum speed was related to decreases in stride length (4.1% in males; 4.9% in females) and increases in contact time (44% to 61% in males; 45% to 71% in females) while stride rates showed minor reductions (2.2% in males; 2.1% in females). The age-related reductions in braking and propulsive ground reaction forces and their rate of development may be primarily responsible for the changes in stride length, contact time, and consequently, speed.[9] In another study, researchers investigated the blood lactate concentrations in a group of male and female masters sprint runners (40-88 years) following competitive 100 m, 200 m and 400 m sprint running.[22] The researchers reported blood lactate concentrations were significantly lower in the sprinters aged between 70-88 years. This implies that decreased ability to generate energy from anaerobic glycolysis may be an additional factor in the age-related decrease in sprinting ability after 70 years.

Similar age-related declines in metabolic power appear to occur in sprint performance in both veteran runners[23] and veteran cyclists.[24] Metabolic power represents the rate at which energy is generated and it is commonly expressed in relation to body mass (watts/kg).[23] The relative metabolic power in 100 m sprint running performance has been reported to decline by 30% (approximately 10% per decade) from 40 to 70 years in competitive male sprint runners.[23] In a cross-sectional study of competitive male cyclists aged 30 to 73 years, Balmer et al. (2005)[24] reported that ramped minute power measured via air-braked cycle ergometry declines by 2.4 watts per year. More recently, Ampratzis et al. (2011)[18] compared absolute values of both 100 m sprint running and inertial cycle ergometry power in male masters endurance cyclists and 100 m sprint runners aged 40 to 65 years. Their findings suggest a similar decline in both sprint cycling power (25.3% per decade) and 100 m sprint running power (25.4% per decade) between the ages 40 and 65 years.

To date, few studies have examined the age-related decline in sprint cycling performance. Martin et al. (2000)[25] reported that maximal cycling sprint power, as measured during 3-4-s all-out efforts using inertial load cycle ergometry, declined by 7.5% per decade in competitive male cyclists aged 30-70 years. The researchers reported the decline in maximal power was reduced to 5% per decade when scaled to lean thigh volume, suggesting a decrease in muscle mass commonly observed in older athletes[9,26,27] may be a major contributor to age-related declines in track cycling performance. It was also found that with age the pedalling rate at which peak power was attained decreased from 124 to 114 rpm and this was thought to reflect age-related reduction in cross-sectional area occupied by fast type II fibers. In addition, Gent & Norton (2012)[28] reported anaerobic peak power measured by 10-s all-out effort using wind-resisted cycle ergometry declined by 8% in both male (n=156) and female (n=17) masters cyclists aged 35-64 years. Taken together, these data suggest cycling peak power declines by 5-8% per decade in masters cyclists.

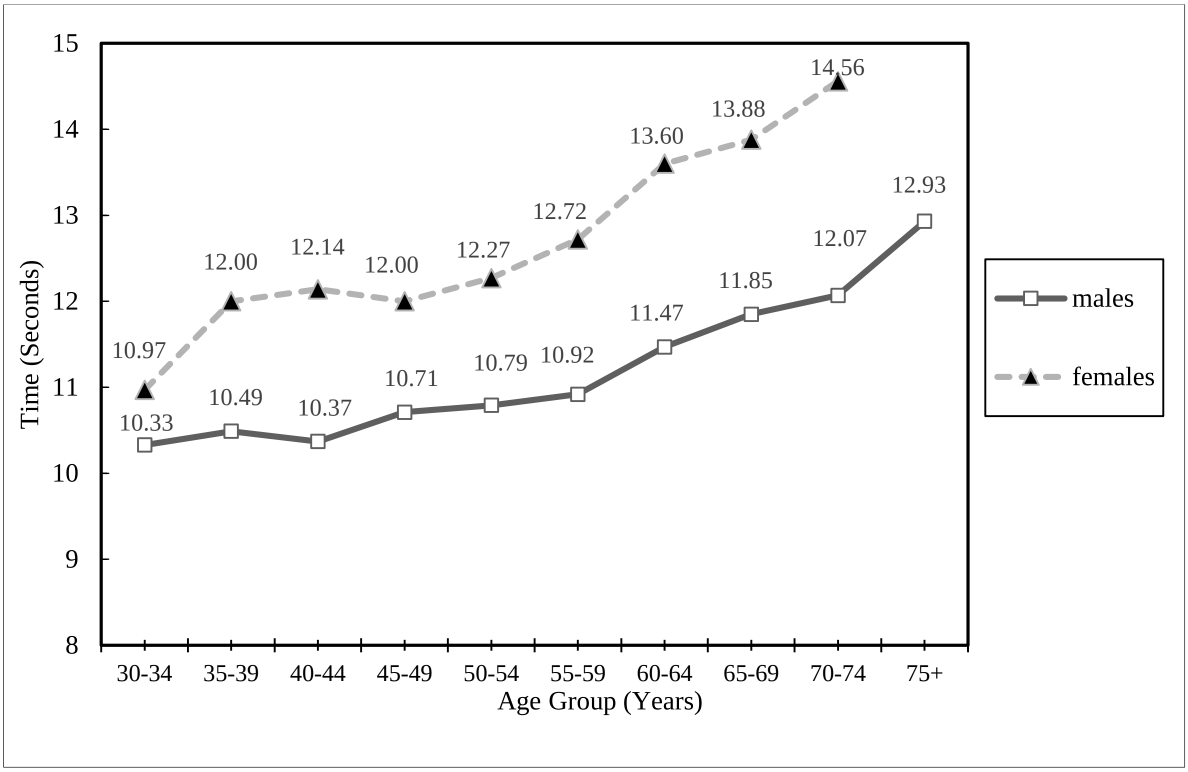

Figure 2.2. Male and female masters flying 200 m track cycling records

We recently examined the current masters 200 m track cycling world records for age-related changes in track cycling performance (see Figure 2.2). The results suggest 200 m track sprint cycling performance declines by 2.8% and 11.2% per decade in males and female track cyclists, respectively. The data in Figure 2.2 appears to suggest a linear decline in flying 200m performance with increasing age in both male and female masters cyclists. Interestingly, cycling times in the 40-44 year category for males and 45-49 year category for females are slightly faster than the male 35-39 year and female 40-44 categories, faster times in these slightly older cohorts may be a result of improved training practices, track-cycling experience or simply, a more athletic group. Taken together, these competition results are in agreement with previous laboratory-based research which reported that in trained cyclists, the decline in anaerobic performance is magnified from 60 years.[25]

2.5.2 The effect of resistance training on sprint running and sprint cycling performance

In athletes of any age, resistance training programs aim to increase muscular strength, neuromuscular power and sprint performance.[29] For masters athletes, to minimise the age-related decline in physiological function, muscle morphology, and neuromuscular function, resistance training programs should include hypertrophy, strength and power training components for the following three reasons.[30] Firstly, muscle force production capacity is proportional to muscle size and hypertrophy resistance training is required to offset the age-related decrease in overall muscle size, strength and power.[13] Secondly, heavier resistance training is required to stimulate fast twitch muscle fibres and motor units, necessary for the improvement of rapid force production.[12] Thirdly, explosive power resistance training exercises and plyometric exercises are required to maximize neuromuscular stimulation and the utilization of muscle-tendon elasticity.[11] However, limited research has investigated the effectiveness of resistance training programs in masters athletes. Indeed, no data are currently available on the effect of either resistance training in masters track-cyclists. Nevertheless, it could be hypothesised, that optimal training in middle- and older-aged sprint cyclists, should follow the guidelines of younger athletes and emphasize resistance training along with sport specific sprint cycle training. The aim of the following section is to review the effectiveness of resistance training programs, in improving sprint performance in masters sprint runners, masters endurance cyclists and masters endurance runners.

2.5.3 Resistance training programs improves sprint performance in masters sprint runners

To date, only two studies have investigated the effects of resistance training on sprint running performance.[13,11] Reaburn & Mackinnon (1994)[13] examined the effect of an eight-week hypertrophy training program on 100 m and 300 m sprint run performance, muscular strength and thigh girth (measured anthropometrically) in eight male sprint-trained runners (54.7 ± 5.5 years). Resistance training took place three times per week on alternative days for an eight week period under the supervision of an experienced and qualified trainer. The participants performed three sets of 12, 10 then 8 repetitions at 80% of 1RM with one minute rest between sets. Exercises selected included leg extensions, leg curls, leg press, half squats, bench press, upright row, bicep curl, triceps push down and abdominal crunches. One-repetition maximum (1RM) capacity was measured every two weeks to adjust training loads appropriately. Subjects were instructed to maintain their normal sprint training regime over the period of the study. At the conclusion of the eight-week study, significant improvements were observed in both 100 m (4%) and 300 m (2%) sprint running performance, quadriceps peak torque (10.3%), hamstring peak torque (12%) and thigh circumference (3.4%).

More recently, Cristea et al (2008)[11] investigated the effect of a 20-week combined sprint, strength and power training program on sprint running performance, morphological and neural adaptations in seven sprint-trained masters track athletes (66.0 ± 3.0 years) who had no previous resistance training experience. The resistance strength and power training program was designed to increase explosive power, strength and muscle hypertrophy, while the sprint training was designed to improve acceleration and maximal running speed. Both resistance training and sprint training sessions were performed twice per week on non-consecutive days. The training program was divided into three cycles. The first cycle involved muscular hypertrophy training protocols (3-4 sets, 8-12 repetitions at 50-70% 1RM). The second and third cycles involved combined plyometric, maximal strength and explosive weight training strength exercises using 4-6 repetitions at 70-85% 1RM, explosive exercises (high-load speed strength used 2-3 sets of 4-6 repetitions at 35-60%

1RM) and plyometric exercises (low-load speed strength using 2-3 sets of 3-10 repetitions). Cycle two used similar exercises and repetition ranges as used in cycle one, but with a general increase in intensity through an increase in load and the addition of plyometric and explosive exercises. In cycle 3, reductions in training volume across both sprint running and resistance training exercises occurred to prevent overtraining.

During the first cycle, the sprint runners performed five 200-250 m runs at 75-85% of maximum sprint running speed. The field sprint sessions were purposefully designed to develop speed endurance, with low volumes to accommodate the resistance training program. To develop acceleration, the athletes performed four 30 m sprints at 80% of maximal effort. During the second and third training cycles, sprint intensity was gradually increased until near maximal speeds were reached. Workouts included two to three repetitions of 30-80 m sprints at 90-98% effort. At the conclusion of the 20-week training period, significant increases were observed in maximum sprint velocity (4%), ground reaction force in the propulsive phase of contact (8%), 1RM squat strength (27%), squat jump (10%), triple jump (4%) and power of reactive jump test (29%), while 60 m sprint run time was significantly faster (2%). Significant increases were also noted in the size of fast twitch muscle fibers (20%) and electromyographic activity of leg extensor muscles during squat jump performance (9%).

Examining the effect of resistance training on sprint performance in masters sprinters is limited by very few recent studies, small samples sizes and short intervention periods. Therefore, based on the available literature, these results suggest that resistance training increases muscle mass, fast twitch muscle fiber size and rapid neural activation, thus, positively affecting strength, power and sprint performance in masters sprint runners.

However, the effects of resistance training on track-cycling performance in masters track-cyclists is not yet known.

2.5.4 Resistance training programs improve running and cycling performance in masters endurance runners and cyclists

Limited research has examined resistance training effects in endurance-trained masters runners and cyclists. Previously, Louis et al. (2010)[31] investigated the effect of a 3-week resistance training program on cycling efficiency in nine endurance-trained male masters cyclists (51.5 ± 5.5 years) and eight endurance-trained younger (25.6 ± 5.9 years) cyclists. Before and after the program, participants performed a 15 minute cycling efficiency test that measured the ratio between external power output and energy expenditure. Following the initial testing protocols, participants performed 10 sets of 10 repetitions at approximately 70% of 1RM load three times per week on a pin-loaded knee extension machine with three minutes rest between each set, whilst maintaining their usual endurance training (7 hours per week). Upon completion of the three-week resistance training program, the endurance-trained masters athletes significantly increased both knee extensor maximal voluntary contraction torque (17.8%) and cycling efficiency (3.0%).

Resistance training may also benefit masters endurance runners, by increasing running economy. In their study, Piacentinni et al (2013)[32] investigated the effects of a 6-week resistance training program on running economy in 16 male and female masters endurance runners. Participants were randomly divided into one of three experimental groups; a maximal strength training group (n=6, 4 male and 2 female, 44.2 ± 3.9 years) who performed 4 sets of 3-4 repetitions at 85-90% of 1RM, two times per week, a resistance training group (n=5, 3 male and 2 female, 44.2 ± 3.9 years) who performed 3 sets of 10 repetitions, at 70% of 1RM two times per week; and a control group (n=5, 5 males, 43.2 ±

7.9 years) who continued with their normal endurance training. Upon completion of the six-week training program, only the maximum strength training group made a significant improvement in running economy at marathon pace (6.1%) and dynamic leg strength (16.3%).

Thus, this limited data available suggests resistance training programs may produce positive effects on both running and cycling performance in masters endurance runners and masters endurance cyclists. However, research has not yet examined the effects of resistance training on track-cycling performance in masters track cyclists. Therefore we can only speculate that improvements in track cycling performance may result from additional resistance training, which limits the age-related decline in muscle mass, muscle strength and neuromuscular power.

2.6 Conclusion

The present review suggests the addition of a resistance training program to sprint running, endurance running or endurance cycling, may lead to additional benefits in performance for masters athletes However, no research to date, has examined the effect of resistance training on track cycling performance in masters track cyclists. Therefore, future research examining the effect of resistance training on track cycling performance in masters track cyclists is needed.

2.7 Practical Applications

- Resistance training may benefit sprint running performance, endurance running and endurance cycling performance in masters athletes.
- The effect of resistance training on track-cycling performance in masters track-cyclists is currently unknown.

- The volume of sprint training may need to be reduced, in order to accommodate for the inclusion of additional resistance training.
- Resistance training programs that incorporate power development, strength development and hypertrophy are recommended.
- Hypertrophy training may be maximised by prescribing loads of 70% of 1RM for 3 sets x 10 repetitions, 2-3 times per week; strength training may be maximised by prescribing loads of 85-90% of 1RM for 2-4 sets x 4-6 repetitions, for two sessions per week and finally power training may be maximised by prescribing loads of 35-60% of 1RM for 2-3 sets x 3-10 repetitions, for two-sessions per week.
- Participation in organised sport and/or training requiring vigorous physical activity, such as resistance and sprint training; pose greater cardiovascular risk to the masters athlete than lower intensity competitive sports, such as golf, billiards and lawn bowling. Therefore, strength and conditioning coaches should be aware of contraindications[33] to exercise before prescribing a resistance and/or sprint training program for a masters athlete.

2.8 References

1. Reaburn, P. Dascombe, B. (2008). Endurance Performance in Masters Athletes. *European Review of Aging and Physical Activity*, 5, 31-42.

2. Lepers, R., Sultana, F., Thierry, B., Hausswirth, C., Brisswalter, J. (2009). Age-Related Changes in Triathlon Performance. *International Journal of Sports Medicine*, 30, 1-6.

3. Tanaka, H., Seals, D.R. (2008). Endurance Exercise Performance in Masters Athletes: Age-Associated Changes and Underlying Physiological Mechanisms. *Journal of Physiology*, 586, 55-63.

4. Hajkowicz, S.A., Cook, H., Wilhelmseder, L., Boughen, N. (2013). The Future of Australian Sport: Megatrends Shaping the Sports Sector over Coming Decades. A Consultancy Report for the Australian Sports Commission. CSIRO, Australia.

5. Wikipedia. World Masters Games. http://en.wikipedia.org/wiki/World_Masters_Games. Accessed 22/12/15

6. Dorel, S., Hautier, C. A., Rambaud, O., Rouffet, D., Van Praagh, E., Lacour, J. R., & Bourdin, M. (2005). Torque and Power-Velocity Relationships in Cycling: Relevance to Track Sprint Performance in World-Class Cyclists. *International Journal of Sports Medicine*, 26, 739-746.

7. Martin, J., Davidson, C.J., Pardyjak, E. (2007). Understanding Sprint-Cycling Performance: The Integration of Muscle Power, Resistance, and Modeling. *International Journal of Sports Physiology and Performance*, 2, 5-21.

8. Davies, C., Sandstrom, E. (1989). Maximal Mechanical Power Output and Capacity of Cyclists and Young Adults. *European Journal of Applied Physiology and Occupational Physiology*, 58, 838-844.

9. Korhonen, M.T. (2009). *Effects of Aging and Training on Sprint Performance, Muscle Structure and Contractile Function in Athletes.* (Doctoral Thesis:

University of Jyväskylä). Retrieved from https://jyx.jyu.fi/dspace/handle/123456789/20350

10. Van Schenau, G.I., de Koning, J.J., de Groot, G. (1994). Optimisation of Sprinting Performance in Running, Cycling and Speed Skating. *Sports Medicine*, 17, 259-275.

11. Cristea, A., Korhonen, M. T., Häkkinen, K., Mero, A., Alén, M., Sipilä, S., Larsson, L. (2008). Effects of Combined Strength and Sprint Training on Regulation of Muscle Contraction at the Whole-Muscle and Single-Fibre Levels in Elite Master Sprinters. *Acta Physiologica*, 193, 275-289.

12. Newton, R. U., Hakkinen, K., Hakkinen, A., McCormick, M., Volek, J., & Kraemer, W. J. (2002). Mixed-Methods Resistance Training Increases Power and Strength of Young and Older Men. *Medicine and Science in Sports and Exercise*, 34, 1367-1375.

13. Reaburn, P., Logan, P., Mackinnon, L. (1994). The Effect of Hypertrophy Resistance Training on Anaerobic Work Capacity in Veteran Sprint Runners. *In 1994 the year of the coach: National Coaching Conference Proceedings*. Canberra, Australia: Australian Sports Commission; 1994:168-172.

14. Watanabe, Y., Tanimoto, M., Ohgane, A., Sanada, K., Miyachi, M., Ishii, N. Increased Muscle Size and Strength from Slow-Movement, Low-Intensity Resistance Exercise and Tonic Force Generation. (2013). *Journal of Aging and Physical Activity*, 21, 71-84.

15. Liu, C.j., Latham., N.K. (2009). Progressive Resistance Strength Training for Improving Physical Function in Older Adults. *The Cochrane Library*.

16. Aagaard, P., Andersen, J.L. (2010). Effects of Strength Training on Endurance Capacity in Top-Level Endurance Athletes. *Scandinavian Journal of Medicine & Science in Sports*, 20, 39-47.

17. Hakkinen, K., Pakarinen, A., Alen, M., Kauhanen, H., Komi, P. (1988). Neuromuscular and Hormonal Adaptations in Athletes to Strength Training in Two Years. *Journal of Applied Physiology*, 65, 2406-2412.

18. Arampatzis, A., Degens, H., Baltzopoulos, V., Rittweger, J. (2011). Why Do Older Sprinters Reach the Finish Line Later? *Exercise & Sport Science Reviews*, 39, 18-22.

19. Korhonen, M.T., Mero, A., Suominen, H. (2003). Age-Related Differences in 100 m Sprint Performance in Male and Female Master Runners. *Medicine and Science in Sports and Exercise*, 35, 1419-1428.

20. Suominen, H. (2011). Ageing and Maximal Physical Performance. *European Review of Aging and Physical Activity*, 8, 37-42.

21. Rittweger, J., Kwiet, A., Felsenberg, D. (2004). Physical Performance in Aging Elite Athletes-Challenging the Limits of Physiology. *Journal of Musculoskeletal and Neuronal Interactions*, 4, 159-160.

22. Korhonen, M.T., Suominen, H., Mero, A. (2005). Age and Sex Differences in Blood Lactate Response to Sprint Running in Elite Master Athletes. *Canadian Journal of Applied Physiology*, 30, 647-665.

23. Rittweger, J., Di Prampero, P.E., Maffulli, N., Narici, M.V. (2009). Sprint and Endurance Power and Ageing: An Analysis of Master Athletic World Records. *Proceedings of the Royal Society B: Biological Sciences*, 276, 683-689.

24. Balmer, J., Potter, C., Bird, S., Davison, R. (2005). Age-Related Changes in Maximal Power and Maximal Heart Rate Recorded During a Ramped Test in 114 Cyclists Age 15-73 Years. *Journal of Aging and Physical Activity*, 13, 75-86.

25. Martin, J., Farrar, R., Wagner, B., Spirduso, W. (2000). Maximal Power across the Lifespan. *Journals of Gerontology: Series A*, 55, M311-M316.

26. Klitgaard, H., Mantoni, M., Schiaffino, S., Ausoni, S., Gorza, L., Laurent-Winter, C., Saltin, B. (1990). Function, Morphology and Protein Expression of Ageing Skeletal Muscle: A Cross-Sectional Study of Elderly Men with Different Training Backgrounds. *Acta Physiologica Scandinavica*, 140, 41-54.

27. Korhonen, M. T., Cristea, A., Alén, M., Häkkinen, K., Sipilä, S., Mero, A., ... & Suominen, H. (2006). Aging, Muscle Fiber Type, and Contractile Function in Sprint-Trained Athletes. *Journal of Applied Physiology*, 101, 906-917.

28. Gent, D.N, Norton, K. (2012). Aging has greater impact on anaerobic versus aerobic power in trained masters athletes. *Journal of Sports Sciences*, 31, 97-103

29. Baechle, T.R, Earle, R.W. (2008). *Essentials of Strength Training and Conditioning.* Chmpaign, IL: Human Kinetics.

30. Del Vecchio, L., Reaburn, P. (2013). Mixed Methods Strength Training for the Masters Athlete: a Review. *Journal of Australian Strength and Conditioning*, 21, 1-10.

31. Louis, J., Hausswirth, C., Easthope, C., & Brisswalter, J. (2012). Strength training improves cycling efficiency in master endurance athletes. *European Journal of Applied Physiology*, *112*, 631-640.

32. Piacentini, M. F., De Ioannina, G., Comotto, S., Spedicato, A., Vernillo, G., & La Torre, A. (2013). Concurrent strength and endurance training effects on running economy in master endurance runners. *The Journal of Strength & Conditioning Research*, 27, 2295-2303.

33. Maron, B. J., Araújo, C. G. S., Thompson, P. D., Fletcher, G. F., de Luna, A. B., Fleg, J. L., & Elosua, R. (2001). Recommendations for Preparticipation Screening and the Assessment of Cardiovascular Disease in Masters Athletes *Circulation*, *103*, 327-334.

3

Manuscript 2 –

Development of a Concurrent Resistance and Sprint Cycling Program.

This chapter is presented with the text formatting and referencing styles required by the peer-reviewed *Strength and Conditioning Journal* in which the paper was published.

Declaration of Co-Authorship and Contribution

Title of Paper	Concurrent resistance training and flying 200-meter time trial program for a masters track cyclist.
Full bibliographic reference for Journal/Book in which the Paper appears	Del Vecchio, L., Villegas, J., Borges, N., Reaburn, P. (2016). Concurrent resistance training and flying 200-meter time trial program for a masters track cyclist. *Strength and Conditioning Journal*.
Status	Accepted and in press

Nature of Candidate's Contribution

Luke Del Vecchio drafted the manuscript in full, edited the manuscript based on co-author feedback, submitted the manuscript, and responded to reviewer comments.

Nature of Co-Authors' Contributions

Jerome Villegas, Nattai Borges and Peter Reaburn reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Please Note the reference format in the following paper is "as per the journals required referencing format".

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Publication of Research Higher Degree Work for Inclusion in the Thesis Procedures

Signature:

Date: 20th June 2016

Concurrent Resistance Training and Flying 200-meter Time Trial Program for a Masters Track-Cyclist.

3.1 Abstract

Participation numbers in masters track-cycling demonstrate the sport of track-cycling is becoming increasingly popular for masters athletes. Despite this, research focused on performance enhancement for masters track-cyclists is lacking. Age-related changes in morphological and neuromuscular factors affect sprint performance and present strength and conditioning coaches with significant challenges. This paper therefore aims to justify the inclusion of a concurrent resistance training and flying 200-m time trial program as an intervention to increase the flying 200-m performance of masters track-cyclists.

3.2 Introduction

3.2.1 Masters track cyclists

Masters athletes are typically older than 35 years of age and systematically train for, and compete in, organized forms of sport specifically designed for older adults (36). Over recent years there has been a significant increase in the number of older athletes continuing to train and compete at high performance levels within both individual (24) and multi-sport events (19) designed for masters athletes. For example, the first World Masters Games (WMG) in Toronto, Canada had 8,305 competitors while the 2013 WMG in Turin, Italy had 15,394 competitors. Participation in masters track-cycling has also increased in recent years, according to Union Cycliste Internationale (UCI). The 2011 masters track cycling world championships attracted over 400 entries from 26 countries while the 2015 event is expected to attract approximately 500 masters track cyclists, from more than 30 countries (43). Taken together, these data suggest the sport of track-cycling is becoming increasingly popular among masters athletes.

3.2.2 Track-cycling

Track-cycling is a generic term for events that take place indoors and outdoors on banked hard track surfaces, ranging in circumferences of 333-m or less (10). Track-cycling can be categorised into either sprint (<1000-m) or endurance (>1000-m) events and principal events can range from 200-m flying sprints to the 50-km points race (10). At the recent 2015 UCI masters world championship event, track-cyclists competed in events, including the flying 200-m sprint, scratch race, team pursuit and points race. The flying 200-m sprint is a time trial that commences from a moving start and is a qualifying event for sprint races or other competitions such as the omnium. Track length determines how many laps a cyclists will take to build up speed prior to crossing the start line. Tactically, the build-up laps aim to accumulate velocity, however, accumulating too much velocity prior to the start can exhaust the legs. Contrastingly, if not enough velocity is accumulated, more energy is required during the event to reach maximum velocity during the event. In younger, elite male track cyclists, flying 200-m times range between 9.3 to 10.3 seconds (10). In contrast, UCI 2015 track records show, male masters track cyclists aged 40 to 60 years flying 200-m times are slower, and range between 10.5 to 11.85 seconds.

3.2.3 Physiological Demands of the Flying 200-m Sprint

The flying 200-m event is a maximal effort sprint event; the primary energy sources utilized consist of the phosphagen and anaerobic glycolytic energy systems (10). The energy system contribution of the flying 200-m time trial in younger cyclists, has been estimated at 40% phosphagen, 55% lactic and 5% aerobic (21). Therefore, large contributions from both anaerobic energy systems are necessary to produce the high power outputs required for success. For example, during a World Cup flying 200-m qualification event, peak and average power outputs for younger cyclists were reported to have ranged between 1020 and

752 watts, whilst speed and pedalling cadence peaked at 63.5 km/hour and 150 revolutions per minute (rpm) respectively (10). The effect of age on the physiological demands of the flying 200-m sprint is an important consideration when planning a strength and conditioning program for a masters track-cyclist. Masters track-cyclists face a decline in anaerobic performance, as a result of age-related biochemical changes such as changes in enzyme activity and decreased lactate production (37). Declining anaerobic performance highlights the need for track-cyclists to undertake additional resistance training, as it has been previously shown (12, 38) that concurrent sprint and resistance training programs slow the decline in anaerobic performance in masters athletes.

Whilst a direct link between track-cycling performance and anthropometric characteristics have not been established, one investigation reported that in a team of younger, elite track cyclists, sprint cyclists were significantly heavier, stronger, and possessed larger chest, arm, thigh and calf girths than endurance cyclists (31). This data suggests sprint-cyclists require greater lean muscle mass than endurance athletes, as performance is dependent on high power outputs and pedalling cadences powered by large thigh and calf muscles. Whilst no research to date has investigated the anthropometric characteristics of masters sprint-cyclists, strength and conditioning coaches can extrapolate this data from younger cyclists (31), to aid the development of a resistance training program for a masters track-cyclist.

3.2.4 Effects of Age on Sprint Performance

Strength and speed based sporting performance decline with age (2); between the ages of 35 to 70 years, there is a linear decline in sprint running performance (5) and Olympic-weightlifting performance (2). Similar declines with age in performance also occur in sprint cycling (29). For example, UCI 2015 track records (44) demonstrate flying 200-m sprint times decline by approximately 5.8% per decade from 30 years to 59 years of age in male, masters track cyclists. Additionally, Ampratzis et al. (3) compared the decline in sprinting power between masters cyclists and masters sprint runners. The researchers reported that from ages 40 to 65 years, both sprint cycling power and sprint running power by declined by 25.3% and 25.4% per decade, The physiological basis of declining sprint performance with age is related to decreases in muscle mass (11), type II muscle fibre cross sectional area (1), impaired cross-bridge kinetics (35) and neural activation (22,11). For example, Martin et al. (29) reported that maximal sprint cycling power declined by 7.5% per decade in males aged 8-70 years, however, when scaled to lean thigh volume, this decline was reduced to 5% per decade. Researchers (22) have also shown masters sprint runners experience an age-related decrease in neural activation during explosive force production. Taken together, these data suggests declining sprint performance with age is associated with morphological and neuromuscular changes.

3.2.5 Resistance Training Improves Sprint Performance in Masters Sprint Runners

Specific resistance training programming for masters athletes involved in sprint training and competition is scarce. Reaburn et al. (38) reported significant improvements in 100m sprint running performance, quadriceps and hamstring peak torque and thigh girth in a group of masters sprint runners upon completing an eight-week resistance training program. In addition, Cristea et al. (12) reported significant improvements in 60m sprint performance, 1RM squat strength and squat jump peak power in a group of sprint-trained masters track athletes after completing a 20-week track sprinting and resistance training program. Thus, this limited research suggests resistance training increases muscle mass, strength, power and sprint performance in masters track runners. However, no research to date has investigated the effects of resistance training in masters track-cyclists.

Previous research in masters runners supports the rationale for including a resistance training program for masters track-cyclists to attenuate age-related losses in muscle mass (12) , bone-density (27), strength and explosive power (22). Furthermore, track-cycling events such as the flying 200-m involve a maximal effort sprint where increased leg strength can improve acceleration and maximum speed (7). Taking these factors into consideration, it seems a logical decision to incorporate a resistance training program into a masters track-cyclists existing training regime. Mixed-methods resistance training programs simultaneously train the three dimensions of muscle characteristics: hypertrophy, maximal force production and maximal power output (32). Moreover, mixed-methods resistance training programs have been shown to effectively increase muscle mass, bone density, muscular strength and explosive force production in healthy older adults, masters sprint runners and masters endurance-cyclists (13, 26, 32).

3.3 Discussion

3.3.1 Program development

The following concurrent resistance training (RT) and track-cycling program (TC) has been devised for a club-level competitive, masters track-cyclist (male, aged 50 years), who is transitioning from the competitive road season to the competitive track season, which begins in 12 weeks. The primary performance goal of this athlete is to improve his flying 200-m time. Typically, the athlete trains with a squad at a local velodrome, but has no individualised training program in place. The first component in the development of the program is the goal setting session. In collaboration with the masters athlete, perceived strengths, weaknesses, realistic long and short term goals and training history should be discussed and recorded. The strength and conditioning coach should consider some important differences between younger and older athletes. These differences include (47):

- Pre-existing health conditions and their impact on regular training and competition.
- A modified work-life balance as many masters athletes are at the peak of their careers at the time of competition and may have difficulties attending or completing training sessions due to work and family commitments.
- A need to balance preferences for social motives/fellowship and competitive achievement.
- Masters athletes bring several years of life and training experiences to the program, and generally like to have their views respected in the goal setting process.

The next stage in the development of the program is to liaise with both the athlete and a medical practitioner, regarding medical history, injuries and suitability to undergo vigorous training and competition. Major health organisations recommend masters-level athletes undergo medical pre-screening assessment of possible cardiovascular complications before commencing training and sports participation to reduce the risk of coronary events (30). Such screening should include a symptom-limited exercise test that approximates the cardiovascular, metabolic and mechanical demands of the intended training and sport (45). In addition, masters athletes should also undergo a thorough, orthopaedic assessment to evaluate the impact of any age-related joint degenerative conditions. Finally, the strength and conditioning coach should perform a movement-based screen to evaluate any movement restrictions and limitations that may impact exercise selections. Simple screens that assess fundamental motor skills required for successful free-weight exercise execution, easily adapted from the physical competency screening test battery (41), include squatting, lunging, hip-hinging, push ups and prone-pull ups. Recent research (27) has shown that masters cyclists are poor users of resistance training in conjunction with their cycling specific training. Therefore, strength and conditioning coaches should be aware that masters cyclists may present with poor movement competencies and limited resistance training experience.

3.3.2 Weekly training schedule

The proposed weekly training schedule (Table 3.1) planned for the masters track-cyclist follows his cycling clubs squad training days. In this case track sessions are held on Sunday mornings (K-1 session: this session has a focus on stationary sprint starts, typically ¼ to ½ lap, emphasizing strength development) and Wednesday evenings (fly-session: this session focuses on high cadence development through the use of flying sprint starts). The masters cyclist will perform his personalised training session with the assistance of the club-coach prior to the squad training session. Resistance training sessions will be performed two times per week, on non-consecutive days, and specifically placed after track-training sessions to avoid any excessive fatigue being carried into track-cycling training. In addition, recovery rides and a regeneration session are placed after resistance training sessions to aid recovery and to maintain endurance levels.

Table 3.1. Concurrent resistance and sprint training weekly schedule

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Session Type	Resistance Training	Road-Based Endurance Recovery ride	Track Training	Resistance Training	Recovery Session	Road-Based Endurance Recovery ride	Track Training
Prescribed Intensity or Activity		50-70% APMHR, 90-110 RPM			Massage or pool based recovery session	50-70% APMHR, 90-110 RPM	

MHR = age predicted maximum heart rate; RPM = revolutions per minute

3.3.3 Flying 200-m Track Program

The aim of the flying 200-m track program is to increase acceleration and maximum speed abilities (Table 3.2). During the general preparation and specific preparation phase, gear loading (the increase of gear size) increases every 4 weeks instead of weekly, to allow for the slower rate of adaptation, commonly observed in master athletes (16). This facilitates strength and power development. In the pre-competition phase, the focus is on speed development with a weekly decrease of gearing load to improve speed cadence and overall track cycling performance and testing time. Selected strategies to achieve increased maximum speed and acceleration capabilities, include 'Over Gear Training', meaning, training with a gear that is larger than the athlete's typical race gear (14). Progressive gearing overload methods have been applied to the program to gradually and systematically increase the stress or demand placed upon a physiological system or organ to avoid the risk of chronic fatigue or injury (16). To ensure each sprint repetition maintains maximal velocity and power; a cluster set method will be been applied to the track-cycling program (18). Cluster sets have rest between repetitions that are contained with a set, also known as inter-repetition rest training method (23). Furthermore, the track-cycling program will also incorporate an ascending progressive gear overload method. Examples of ascending progressive gearing overload set structures on Wednesday K1 training session and Sunday Fly session, can be seen by the increasing gearing load between each cluster sets. Seated sprints are combined with standing sprints on Tuesday session (K-1, 9 standing starts, seated effort cluster set). Seated acceleration technique are also an important component of the program. The approach, combining work on techniques and strength, is built into the weekly track training program, including a progressive gearing overload as strength develops and progresses.

Table 3.2. Concurrent resistance and sprint training exercise selections and progressions

Table 2 Exercise Selections and Progressions			
	GPP	SPP	PCP
Functional warm up/motor skill development	5-minutes stationary cycling foam roller, crab-walks, bar or broomstick sequence: Squat-lunges-Romanian deadlift-shoulder press-push up-prone pull up (knees).	foam roller, crab-walks, bar or broomstick sequence: overhead squat-overhead Lunges-good mornings-push press-push up-prone pull up (knees).	Foam roller, crab-walks, bar or broomstick sequence: burgener barbell warm up.
Power		bilateral horizontal leg press throws	unilateral horizontal leg press throws
Plyometrics		squat jumps in place, lunge jumps in place, box jumps (2-3 stairs high)	alternating split squat jumps, single-leg box push offs, alternating single-leg box push offs.
Maximum strength		unilateral 45 degree leg Press	unilateral 45 degree leg press
Hypertrophy	bilateral 45 degree, leg press curls, standing calf raises, dumbbell hip flexions, chest presses, 45 degree bench prone-rows	leg curls, dumbbell hip flexions, seated calf raises, chest press, 45 degree bench prone-rows	leg curls, dumbbell hip flexions, seated calf raises, chest press, 45 degree bench prone-rows
Trunk stability	front and side bridges on knees, prone back raises	modified Curl ups, 4-point back extensions, full side bridge	advanced curl ups, 45 degree bench back extensions, dynamic side bridge

GPP = general preparation phase; SPP = specific preparation phase PCP = pre-competition phase

3.3.4 Resistance training program

The following suggested resistance training program addresses several of the age-related factors affecting sprint performance in masters athletes and includes: hypertrophy training to offset age-related decreases in muscle mass, heavy strength training to reduce the loss of fast twitch muscle fibers and motor units, and ballistic power exercises and plyometrics to maximize rate of rapid force generation. In this hypothetical situation, we are assuming the masters track-cyclist has a minimal resistance training age, and thus the exercise selection is focused on basic strength building exercises (Table 3.3) to limit the chance of injury. Free-weight motor skill development will be incorporated into the warm up to develop lifting competencies for later programming stages.

This present program is adapted from Cristea et al. (11) and suitably modified to meet the needs of a masters track-cyclist. The general preparation phase emphasises low intensity high volume hypertrophy exercises to prepare the masters track-cyclist for more intensive training in the following phases. In the specific and pre-competition phases, maximal strength and ballistic power exercises are undertaken and alternated within a week to allow recovery from different types of training stress. The progression in training intensity across the latter stages of the training program is aimed at inducing an overload stimulus and to peak maximal strength and power by the end of the training period. Training loads are determined from 3-5 RM testing results of each exercise, performed every 4 weeks to monitor progress and adjust training loads accordingly.

Exercise selection should focus on the primary muscle groups and joint actions that power the pedal stroke. In the power phase or downstroke the hip, knee and ankle joints extend simultaneously (40), whilst in the recovery phase or upstroke, a combination of knee flexion and hip flexion help bring the pedal back to the top (40). Throughout this motion, a rigid trunk position and a strong grip on the handle bars from the arms and chest, enable proper force transfer between upper and lower body (39). Standing positions are also adopted during flying-200-m events and research indicates that whilst maintaining a standing position there is increased gluteus maximus activation to stabilise the pelvis as it is no longer supported by the saddle (25). Therefore, exercise selections should target the hip flexors (Figure 3.1), hip extensors, knee extensors and ankle joint plantar flexors (Figure 3.2), additionally, plyometric and ballistic exercises specific for track-cycling are incorporated, as part of the power training component. These exercises are progressed over the training period from low intensity double leg hops and jumps to single leg alternating lunge jumps and box hops (4,9).

Figure 3.1. Cycling specific exercise: dumbbell hip flexor

Figure 3.2. Cycling specific exercise: single leg, leg press

Table 3.3. Flying 200-m track cycling program

	K- 1 Session (Sunday)	Fly-Session (Wednesday)
GPP	Warm up: ● 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h Conditioning phase (@80% of max speed): ● 3-5 minutes active recovery between reps ● 15 minutes passive recovery between sets Set 1: ● 3 x 65m @ 92 standing start. 1 x 100m seated from 20kph Set 2: ● 3 x 65m @ 94 standing start. 3 minutes active recovery between repetitions ● 1 x 200m seated from 20kph Set 3: 3 x 65m @ 96 standing start. ● 1 x 333m seated from 30kph Cool-down: ● 10-15 laps at a very low intensity or 5-10 minutes on rollers	Warm up: ● 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h Conditioning phase (@80% of max speed): ● 3-5 minutes active recovery between reps ● 15 minutes passive recovery between sets Set 1: ● 1 x Flying 100m @ 94 ● 1 x Flying 100m @ 96 ● 1 x Flying 100m @ 98 Set 2: ● 1x flying 33m @98 ● 1x flying 33m @100 Cool-down: ● 10-15 laps at a very low intensity or 5-10 minutes on rollers
SPP	Warm up: ● 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h ● Plyometrics Conditioning phase (@ 90% max speed): ● 3-5 minutes active recovery between reps ● 15 minutes passive recovery between sets Set 1:	Warm up: ● 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h ● Plyometrics Conditioning phase (@ 90% max speed): ● 3-5 minutes active recovery between reps ● 15 minutes passive recovery between sets Set 1:

	• 3 x 65m @ 96 standing start. • 1 x 100m seated from 20kph Set 2: • 3 x 65m @ 98 standing start. • 1 x 200m seated from 20kph Set 3: 3 x 65m @100 standing start. • 1 x 333m seated from 30kph Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers	• 1 x Flying 100m @ 98 • 1 x Flying 100m @ 100 • 1 x Flying 100m @ 102 Set 2: • 1x flying 33m @102 • 1x flying 33m @104 Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers
PCP	Warm up: • Rollers 10 minutes, including several short sprints • Plyometrics Conditioning phase (@90-98% max speed): • 3-5 minutes active recovery between reps • 15 minutes passive recovery between sets Set 1: • 3 x 65m @ 98 standing start. • 1 x 100m seated from 20kph Set 2: • 3 x 65m @ 96 standing start. • 1 x 200m seated from 20kph Set 3: 3 x 65m @194 standing start. • 1 x 333m seated from 30kph Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers	Warm up: • Rollers 10 minutes, including several short sprints • Plyometrics Conditioning phase (@90-98% max speed): Set 1: • 1 x Flying 100m @ 100 • 1 x Flying 100m @ 98 • 1 x Flying 100m @ 96 Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers

GPP = general preparation phase; SPP = specific preparation phase; PCP = pre-competition phase; K1= started gate sprints; Fly-Session = all sprints completed from a flying-start

Table 3.4. Week Resistance training program

Phase	**GPP**	**SPP**		**PCP**	
Reps	H: 12-15	H: 10-12		H: 8-12	
		S: 6-8		S: 5-3	
		P: 5		P: 5	
		Ply: 10-12		Ply: 6	
Sets	H: 4	H: 2-3		H: 1-2	
		S: 3		S: 3	
		P: 3		P: 3	
		Ply: 3-4		Ply:4-5	
Load (%1RM)	H: 50-60%	H: 60-70%		H:70-80%	
		S: 80-85%		S:87-93%	
		P: 30-40%		P: 40-50%	
		Ply: double leg jumps		Ply: single leg jumps	
Rest Periods	1 minute	Hyp: 1 min	Hyp: 1 min	Hyp: 1 min	EE/S/Ply: 2-3mins
		P/S/Ply: 2-3min	P/S/Ply: 2-3min	P/S/Ply: 2-3min	

H = hypertrophy; S = strength; P = power exercises; Ply = plyometrics; FC = foot contacts; GPP = general preparation phase; SPP = specific preparation phase; PCP = pre-competition phase.

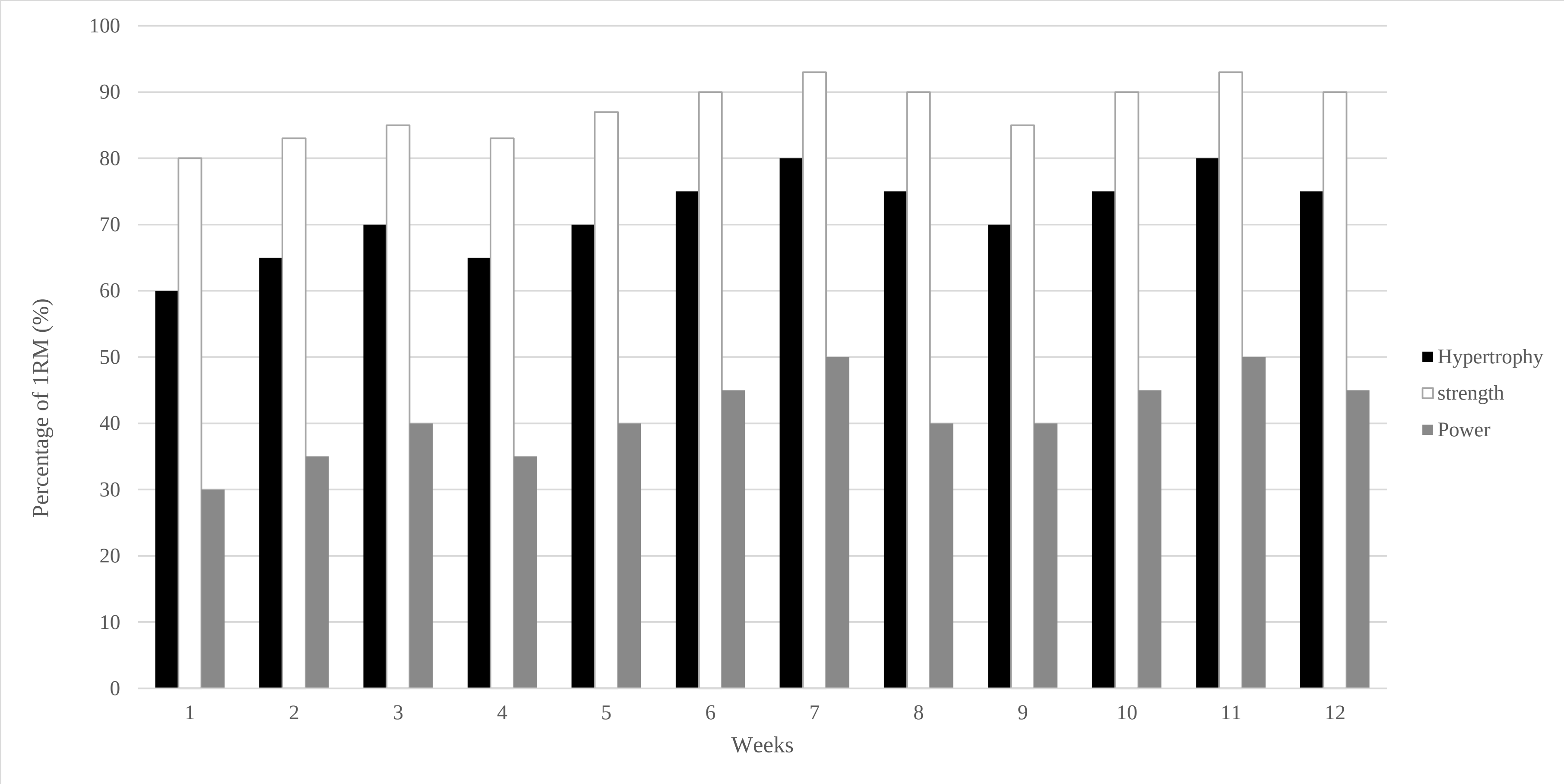

Figure 3.3. Resistance training periodization

3.4 Periodization

In order to reduce the potential for overtraining and to optimize training adaptation, a 3:1 summated microcycles periodization strategy (Table 3.2) will be incorporated into both track-cycling and resistance training programs (34). The RT program will use three-weeks of increasing intensity (%1RM) followed by an unloading week. In contrast, the TC program will keep the intensity (gear resistance) the same, but greatly reduce the volume by 40 to 60% (e.g., Tuesday K-1 day having 3 X 1 single cluster set instead of 3 X 3 and a single 200-m fly test effort on the Sunday session instead of the fly Sunday session). Periodization is especially important for master athletes, who unlike younger athletes, require increased time for recovery, following intense exercise (8). To monitor weekly training loads and to ensure excessive fatigue is prevented, the session RPE method can be used to evaluate the masters athletes tolerance to training, by calculating and analysing training loads over time (16).

3.5 Testing & Evaluation

The program is evaluated when the athlete is monitored by the strength and conditioning coach each session. Tracking anthropometric and performance changes is critical to ensure athlete progression, particularly the masters athlete, who is vulnerable to age-related morphological and neuromuscular changes. Anthropometric assessments need to track changes in muscle mass, body fat and if possible, bone density, depending on the access to a DEXA (dual energy x-ray absorptiometry) scan to provide accurate detailed information on bone density, muscle mass and body fat percentage. Other low cost field tests can also be used, including

- Girth measurements (arm, chest, thigh, calf)

- Skinfold measurements (chest, mid-abdominal, mid-thigh)

Although 1RM testing is considered safe for older populations, including masters athletes (30), we suggest strength and conditioning coaches, use either a 3 or 5 RM test as the majority of masters athletes are unlikely to have undergone 1RM testing before. Additionally, the majority of masters athletes are unlikely to have undergone power assessments such as countermovement or squat jump testing, nor ballistic power assessments such as leg press throws. Thus, familiarization sessions will be required to improve the reliability of performance testing sessions (33). Recommended performance tests, again depending on access, may include more sophisticated laboratory measures including forceplates, isokinetic dynamometer derived force and power profiles and also lower cost options, including:

- bilateral and unilateral leg press 3RM
- chest press/bench row 3RM
- Leg press throw power/velocity – accelerometer based
- Squat jump and Countermovement jump – contact mat, accelerometer based
- 10 second peak power – stationary bike

3.6 Conclusions

Despite the limited research supporting the use of mixed-methods resistance training for masters sprint-runners and sprint-cyclists, improvements in flying 200-m track-cycling performance can be acquired by the inclusion of a carefully constructed track-cycling and mixed-methods resistance training program. Age-related morphological and neuromuscular changes present significant challenges for the masters track-cyclist. Strength and conditioning coaches should be aware of these factors when designing a strength and conditioning program for a masters track-cyclist and current evidence suggests the inclusion of a concurrent resistance training and flying 200-m time trial program can be beneficial to the flying 200-m performance of a masters track-cyclist.

3.7 References

1. Aagaard P, Magnusson PS, Larsson B, Kjær M, and Krustrup P. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. *Med Sci Sports Exerc* 39: 1989-1996, 2007.

2. Anton MM, Spirduso WW, and Tanaka H. Age-related declines in anaerobic muscular performance: weightlifting and powerlifting. *Med Sci Sports Exerc* 36: 143-147, 2004.

3. Arampatzis A, Degens H, Baltzopoulos V, and Rittweger J. Why do older sprinters reach the finish line later? *Exerc Sport Sci Rev* 39: 18-22, 2011.

4. Baechle T and Earle RW. *Essentials of Strength Training and Conditioning* (pp. 413-427) Champaign, IL: Human Kinetics. 2008.

5. Baker A, Tang Y, and Turner M.Percentage decline in masters superathlete track and field performance with aging. *Exp Aging Res* 29: 47-65, 2003.

6. Baker AB and Tang YQ. Aging performance for masters records in athletics, swimming, rowing, cycling, triathlon, and weightlifting. *Exp Aging Res* 36: 453-477, 2010.

7. Blazevich AJ and Jenkins DG. Effect of the movement speed of resistance training exercises on sprint and strength performance in concurrently training elite junior sprinters. *J Sports Sci* 20: 981-990, 2002.

8. Borges N, Reaburn P, Driller M, and Argus C. Age-related changes in performance and recovery kinetics in masters athletes. *J Aging Phys Act* 24*:*149-157, 2016.

9. Chu DA. *Jumping into plyometrics.* Champaign, IL: Human Kinetics (pp.147-148) 1998.

10. Craig NP and Norton KI. Characteristics of track cycling. *Sport Med* 31: 457-468, 2001.

11. Cristea A. Effects of Ageing and Physical Activity on Regulation of Muscle Contraction. Doctoral Thesis, Uppsala University: 14-16, 2008.

12. Cristea A, Korhonen M, Häkkinen K, Mero A, Alén M, Sipilä S, Viitasalo J, Koljonen M, Suominen H, and Larsson L. Effects of combined strength and sprint training on regulation of muscle contraction at the whole-muscle and single-fibre levels in elite master sprinters *Acta Physiol* 193: 275-289, 2008.

13. Del Vecchio L and Reaburn P. Mixed methods strength training for the masters athlete: a review. *J Aust Strength Cond* 21: 1-10, 2013.

14. Dorel S, Hautier C, Rambaud O, Rouffet D, Van Praagh E, Lacour J, and Bourdin M. Torque and power-velocity relationships in cycling: relevance to track sprint performance in world-class cyclists. *Int J Sports Med* 26: 739-746, 2005.

15. Fell J and Williams AD. The effect of aging on skeletal-muscle recovery from exercise: possible implications for aging athletes. *J Aging Phys Act* 16: 97-115, 2008.

16. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, and Dodge C. A new approach to monitoring exercise training. *J Strength Cond Res* 15: 109-115, 2001.

17. Fry RW, Morton AR, and Keast D. Periodisation and the prevention of overtraining. *Can J Sport Sci* 17: 241-248, 1992.

18. Haff GG, Hobbs RT, Haff EE, Sands WA, Pierce KC, and Stone MH. Cluster training: a novel method for introducing training program variation. *Strength Cond J* 30: 67-76, 2008.

19. Hajkowicz SA, Cook H, Wilhelmseder L, and Boughen N. The Future of Australian Sport: Megatrends shaping the sports sector over coming decades. A Consultancy Report for the Australian Sports Commission. CSIRO, Australia: 15-20, 2013.

20. Harridge S, Magnusson G, and Saltin B. Life-long endurance-trained elderly men have high aerobic power, but have similar muscle strength to non-active elderly men. *Aging Clin Exp Res* 9: 80-87, 1997.

21. Jeukendrup AE, Craig NP, and Hawley JA.The bioenergetics of world class cycling. *J Sci Med Sport* 3: 414-433, 2000.

22. Korhonen MT, Cristea A, Alén M, Häkkinen K, Sipilä S, Mero A, Viitasalo JT, Larsson L, and Suominen H. Aging, muscle fiber type, and contractile function in sprint-trained athletes. *J Appl Physiol* 101: 906-917, 2006.

23. Lawton TW, Cronin JB, and Lindsell RP.Effect of interrepetition rest intervals on weight training repetition power output. *J Strength Cond Res* 20: 172-176, 2006.

24. Lepers R, Sultana F, Thierry B, Hausswirth C, and Brisswalter J.Age-related changes in triathlon performance *Int J Sports Med* 30: 1-6, 2009.

25. Li L and Caldwell GE. Muscle coordination in cycling: effect of surface incline and posture. *J Appl Physiol* 85: 927-934, 1998.

26. MacGregor C, Del Vecchio L, Meekin J, Korhonen MT, and Reaburn P. A pilot study examining the effect of 12 weeks of resistance and sprint cycle training on bone mineral content in veteran endurance cyclists. Proceedings of the 25th Annual ANZBMS Conference, Hobart, Australia, 1st – 4th November, 2015.

27. MacGregor C, Reaburn P, and Korhonen M. Training modalities of masters cyclists: An Australian study. Presented at European College of Sport Science 19th Annual Congress, Amsterdam, Holland, 2014.

28. Maron BJ, Araújo CGS, Thompson PD, Fletcher GF, de Luna AB, Fleg JL, Pelliccia A, Balady GJ, Furlanello F, and Van Camp SP. Recommendations for Preparticipation Screening and the Assessment of Cardiovascular Disease in Masters Athletes: An Advisory Statement for Healthcare Professionals From the Working

Groups of the World Heart Federation, the International Federation of Sports Medicine, and the American Heart Association Committee on Exercise, Cardiac Rehabilitation, and Prevention. *Circulation* 103: 327-334, 2001.

29. Martin J, Farrar R, Wagner B, and Spirduso W. Maximal power across the lifespan. *J Gerontol A Biol Sci Med Sci* 55: M311-M316, 2000.

30. Maud PJ and Foster C. *Physiological Assessment of Human Fitness* (pp 4-8). Champaign, IL: Human Kinetics, 2006.

31. McLean BD and Parker AW. An anthropometric analysis of elite Australian track cyclists. *J Sports Sci* 7: 247-255, 1989.

32. Newton RU, Hakkinen K, Hakkinen A, McCormick M, Volek J, and Kraemer WJ. Mixed-methods resistance training increases power and strength of young and older men. *Med Sci Sports Exerc* 34: 1367-1375, 2002.

33. Phillips WT, Batterham AM, Valenzuela JE, and Burkett LN. Reliability of maximal strength testing in older adults. *Arch Phys Med Rehabil* 85: 329-334, 2004.

34. Plisk SS and Stone MH. Periodization strategies. *Strength Cond J* 25:19-37, 2003.

35. Power GA, Minozzo FC, Spendiff S, Filion M-E, Konokhova Y, Purves-Smith M, Pion C, Aubertln-Leheudre M, Morais JA, and Herzog W. Reduction in single muscle fiber rate of force development with aging is not attenuated in world class older masters athletes. *Am J Physiol Cell Cell Physiol* 15:318-327, 2016.

36. Reaburn P and Dascombe B. Endurance performance in masters athletes. *Eur Rev Aging Phys Act* 5: 31-42, 2008.

37. Reaburn P and Dascombe B. Anaerobic performance in masters athletes. *Eur Rev Aging Phys Act* 6: 39-53, 2009.

38. Reaburn P, Logan P, and Mackinnon L. The effect of hypertrophy resistance training on anaerobic work capacity in veteran sprint runners. *In 1994 the year of the coach:*

National coaching conference proceedings. Canberra, Australia: Australian Sports Commission 168-172, 1994.

39. Segerström ÅB, Holmbäck AM, Elzyri T, Eriksson K-F, Ringsberg K, Groop L, Thorsson O, Wollmer P. Upper body muscle strength and endurance in relation to peak exercise capacity during cycling in healthy sedentary male subjects. *J Strength Cond Res* 25: 1413-1417, 2011.

40. So RC, Ng JK-F, and Ng GY. Muscle recruitment pattern in cycling: a review. *Phys Ther Sport* 6: 89-96, 2005.

41. Tanner R and Gore C. *Physiological Tests for Elite Ahletes.* Human Kinetics, 2013.

42. Trappe S, Costill D, Goodpaster B, and Pearson D. Calf muscle strength in former elite distance runners. *Scand J Med Sci Sports* 6: 205-210, 1996.

43. Union Cycliste Internationale. History of the world masters track championships. http://www.cyclingmasters.com/site/index.php?option=com_content&view=article&id=37&Itemid=241. Accessed 22/12/15

44. Union Cycliste Internationale. 2015 Masters Track Records. http://www.uci.ch/mm/Document/News/NewsGeneral/16/60/58/MastersBestPerformances_Hommes_20150619_Neutral.pdf. Accessed 22/12/15

45. Whiteson JH, Bartels MN, Kim H, and Alba AS. Coronary artery disease in masters-level athletes. *Arch Phys Med Rehabil* 87: 79-81, 2006.

46. Wikipedia. World Masters Games. http://en.wikipedia.org/wiki/World_Masters_Games. Accessed 22/12/15

47. Young BW, Callary B, and Niedre PC. Exploring novel considerations for the coaching of masters athletes. *Int J Sports Sci Coach* 1: 86-93, 2014.

4

Manuscript 3 –

Reliability of Explosive Muscular Power Testing in Masters Athletes

This chapter is presented with the text formatting and referencing styles required by the peer-reviewed *La Prensa Medica Argentina* in which the paper was published.

Declaration of Co-Authorship and Contribution

Title of Paper	Reliability of squat jump and countermovement jump performance in masters athletes.
Full bibliographic reference for Journal/Book in which the Paper appears	**Del Vecchio,** L. Borges, N., Reaburn, P., Korhonen, M.T. (2016). Reliability of squat jump and countermovement jump performance in masters athletes. *La Prensa Medica Argentina*. 102(2), 1-5.
Status	Published

Nature of Candidate's Contribution

Luke Del Vecchio conceived the research idea, designed the experiment, collected data, , statistically analysed the data, drafted manuscript in full, edited the manuscript based on co-author feedback, submitted the manuscript, and responded to reviewer comments.

Nature of Co-Authors' Contributions

Peter Reaburn and Marko Korhonen refined the experimental design, reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Nattai R. Borges contributed to data collection reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Please Note the reference format in the following paper is "as per the journals required referencing format".

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Publication of Research Higher Degree Work for Inclusion in the Thesis Procedures.

Signature:

Date: 20th June 2016

Reliability of squat jump and countermovement jump performance in masters athletes.

4.1 Abstract

Despite their widespread use in performance assessment in younger athletes, the reliability of squat jump (SJ) and countermovement jump (CMJ) assessments has not been reported in masters athletes. The aim of this study was to assess the test-retest reliability of the SJ and CMJ in endurance-trained masters cyclists. Ten endurance-trained masters cyclists (50.8 ± 6.0 years) were recruited and asked to perform SJ and CMJs on two separate occasions five days apart. Moderate to high intraclass correlations (0.56 to 0.95) were observed for SJ peak power (PP), peak power·body mass^{-1} (PP·BM^{-1}), peak force (PF), peak force·body mass^{-1} (PF·BM^{-1}) and concentric rate of force development (CRFD). High intraclass correlations (>0.8) were observed for CMJ PP, PP·BM^{-1}, PF, PF·BM^{-1} and CRFD. The SJ coefficient of variation (CV) for all SJ variables ranged from 5.6 to 27.5% and for CMJ variables ranged from 3.9 to 12.2%. Overall, PP and PP·BM^{-1} were the most reliable variables for both SJ and CMJ. In contrast, CRFD of both SJ and CMJ displayed the most variability. The technical error of measurement (TEM) varied between 4.7 to 28.4% for SJ and 5.4 to 17.7% for CMJ depending on the variables examined. The results of the current study provides important implications for intervention studies examining strength and power variables in older athletes.

Key Words: Masters endurance-cyclist, squat jump, countermovement jump, test-retest reliability, technical error of measurement, coefficient of variation, Intraclass correlation coefficient

4.2 Introduction

Force and power are well known determinants of sports performance [1,2]. The assessment of both variables is central to the analysis of physical condition and training status [3]. Historically, lower limb force and power have been evaluated through both countermovement jump (CMJ) and squat jump tests (SJ) [4]. The SJ test provides information on lower limb power development during the concentric (upward) phase of the jump.[5] In contrast, the CMJ test provides information on lower limb power development during both the eccentric (down phase) and concentric phase under the influence of both the slow-stretch shortening cycle and low stretch load condition [5].

In aging populations, both SJ and CMJ performance have been used to assess both the muscle strength and power [6,7] and the efficacy of strength training interventions [8-10]. The use of CMJ and SJ is also prevalent in the assessment of force and power of masters athletes who are defined as individuals who systematically train to participate in sports competitions specifically designed for older adults [11]. For example, in masters runners CMJ performance has been used to examine the effects of age on jumping power [12, 13] and to examine age-related declines in peak power in highly-trained masters track and field athletes [14].

Given the widespread use of SJ and CMJ tests, awareness of the variability that may exist within these tests is critical to be able to discriminate between random error and real differences as a result of training interventions [15]. While the reliability of both the SJ and CMJ test has been examined in both younger athletes [5,16] and healthy, middle-aged and older men and women [15,17,18], no studies have examined the reliability of CMJ or SJ tests in older athletes. Importantly, age-related changes in the inter-muscular coordination patterns [19] and neuromuscular function related to CMJ performance in endurance-trained masters cyclists [19] suggest there may be higher variability in both SJ and CMJ than observed in younger athletes. Therefore, the aim of the present study was to assess the test-retest reliability of both SJ and CMJ performance in endurance-trained masters cyclists.

4.3 Methods

4.3.1 Subjects

Ten healthy male masters road cyclists were recruited as subjects and provided written informed consent to participate in the study. Demographic data for all participants is presented in Table 4.1. The participants were required to be involved in regular cycling training and/or competition for a minimum of two years and to be achieving a minimum of eight hours of endurance cycling training per week. All participants underwent pre-exercise screening to ensure they had no established cardiovascular, metabolic or respiratory disease or signs and symptoms of these conditions (Sports Medicine Australia, 2011). This study was given ethical clearance by the Central Queensland University (CQUniversity) Human Ethics Research Panel in accordance with the Helsinki declaration.

Table 4.1. Physical characteristics and total weekly training

	Mean ± SD
Age (years)	50.8 ± 6.0
Height (m)	1.79 ± 0.09
Weight (kgs)	84.4 ± 9.7
Training hours (hr/week)	8.2 ± 1.0

Figure 4.1. Force plate used for the examination of peak power, force and rate of force development during squat jump and countermovement jump

4.3.2 Study design

All testing occurred at the CQUniveristy biomechanics laboratory under standard laboratory conditions. Test-retest reliability sessions were conducted with endurance-trained masters cyclists who were asked to perform SJ and CMJs on two separate occasions five days apart.

4.3.3 Procedures

On their first visit, participants were familiarised with all testing procedures followed by collection of anthropometric data and initial SJ and CMJ tests. Stature (m) and body mass (kg) were measured with a stadiometer and scales, respectively (Seca, Birmingham, UK).

Prior to all jump testing a 15-minute warm up that included 5 minutes of cycling at 50 watts on a cycle ergometer (Velotron Dynafit Pro, RaceMate, Seattle, WA, USA), followed by 10 body weight squats, 10 heel raises, 5 SJs and 5 CMJs all undertaken at moderate intensity. All jumps were performed and analysed using a force plate (Advanced Medical Technology Inc. BP400800-200, Watertown, USA) at a sample rate of 1,000 Hz. The analogue signal was converted to a digital signal using a powerlab 30 series data acquisition system (AD Instruments, Sydney, Australia). The vertical force-time data were filtered using a fourth-order butterworth low-pass filter with a cut-off frequency of 17 Hz.

Following the warm up, participants were allowed five minutes of passive rest before performing the SJ tests. Participants were required to reach the starting position of 90º of knee flexion which was measured with a goniometer (12-1000, Baseline®, NY, USA). After maintaining this squat position for 3 seconds, participants were asked to apply force into the force platform as fast as possible and jump for maximum height. Countermovement was verbally discouraged and carefully checked after each trial using the time-force curves. At landing, subjects were required to touch down with the same leg position as take off. If each of these requirements were not met, the trial was repeated [21]. Each trial was followed by 2 minutes of passive rest. The mean of three jumps was selected for further analysis.

The CMJ started from a full erect standing position. Participants were instructed to perform a fast downward movement (to approximately 90º knee flexion) immediately followed by a fast upward movement, and to jump as high as possible. Hands were kept on the hips to minimize any influence of the arm swing [17]. Each trial was followed by 2 minutes of passive rest and the mean of three jumps was selected for further analysis.

The force-time data examined during the SJ and CMJ included: peak power (PP), peak power·body mass^{-1} (PP·BM^{-1}), peak force (PF), peak force·body mass^{-1} (PF·BM^{-1}), and concentric rate of force development (CRFD). The peak force was calculated as the maximum force achieved over the force-time curve during the jump. Concentric rate of force development (CRFD) is the tangent (derivative) of the force curve during the concentric phase. The vertical velocity that was calculated from the integration of the force-time trace was used in the calculation of peak power. The vertical force was multiplied by the velocity throughout the propulsive phase of the jump to calculate power; the maximum value was taken as peak power.

4.3.4 Statistical analyses

Descriptive statistics (mean ± SD) were calculated for all data. We determined test-retest reliability using coefficient of variation percentage (CV), Intraclass correlation coefficients (ICC) with 95% confidence intervals and technical error of measurement percentage (TEM). Similar reliability studies (Cormack et al., 2008; Ditroilo et al., 2011; Holsgaard Larsen et al., 2007) were used to interpret the CV values with an analytical goal set at 10% or less for reliability. Data were log-transformed [22,23] and analysed using an Excel spreadsheet for reliability [24].

4.4 Results

The reliability parameters (ICC, CV and TEM) are presented for six variables (PP, PP·BM^{1}, PF, PF·BM^{-1}, CRFD, JH) for both the SJ (Table 4.2) and CMJ (Table 4.3). The variables with the highest level of reliability for SJ were PP and PP·BM^{-1}; for CMJ, PF and PF·BM^{-1} demonstrated the highest level of reliability (ICC >0.90). The CV for SJ variables ranged between 5.6-27.5%. For the CMJ, the CV ranged between 3.5 – 12.2%. The TEM for the SJ variables ranged between 4.7 and 28.4%; for CMJ variables, TEM ranged between 5.4 and 17.7%.

Table 4.2. Reliability of SJ variables measured in masters cyclists with 95% CI

	CV% (95% CI)	**ICC (95% CI)**	**TEM (%)**
PP (W)	5.6 (3.8-10.5)	0.95 (0.80-0.99)	5.4
PP·BM^{-1}(W·kg)	5.6 (3.8-10.5)	0.94 (0.77-0.98)	9.0
PF (N)	17.3 (11.6-33.9)	0.56 (-0.07-0.87)	4.7
PF·BM^{-1} (W·kg)	17.3 (11.6-33.9)	0.56 (-0.06-0.87)	4.7
PCRFD (N/s)	27.5 (18.2-55.7)	0.78 (0.34-0.94)	28.4
JH (cm)	12.4 (8.4-23.9)	0.77 (0.32-0.94)	12.0

PP = peak power, PP·BM^{-1}= peak power·body mass^{-1} peak power·body mass^{-1}, PF = peak force, PF·BM^{-1} = peak force·body mass^{-1}, PCRFD = peak concentric rate of force development, JH = jump height, CV% = coefficient of variation expressed as a percentage, CI = confidence interval, TEM = technical error of measurement expressed as a percentage.

Table 4.3. Reliability of CMJ variables measured in masters cyclists with 95% CI.

	CV (95% CI)	**ICC (95% CI)**	**TEM (%)**
PP (W)	9.5 (6.6-17.9)	0.93 (0.75-0.98)	9.0
PP·BM^{-1}(W·kg)	9.5 (6.8-16.0)	0.93 (0.75-0.98)	5.4
PF (N)	3.9 (2.7-7.3)	0.94 (0.78-0.98)	17.7
PF·BM^{-1} (W·kg)	3.9 (2.7-7.3)	0.94 (0.78-0.98)	12.0
PCRFD (N/s)	12.2 (8.2-23.3)	0.95 (0.81-0.99)	9.4
JH (cm)	15.7 (10.5-30.4)	0.72(0.22-0.92)	11.0

PP·BM^{-1}= peak power·body mass^{-1} peak power body mass^{-1}, PF = peak force, PF·BM^{-1} = peak force·body mass, PCRFD = concentric rate of force development, JH = jump height, CV = coefficient of variation expressed as a percentage, CI = confidence interval, TEM = technical error of measurement expressed as a percentage.

4.5 Discussion

The present study is the first to assess the reliability of a number of variables related to both SJ and CMJ performance in masters athletes. The major findings from the study are: (a) SJ variables showed moderate to excellent reliability in endurance-trained masters cyclists with PP and PP·BM^{-1} the most reliable variables, while PF, PF·BM^{-1}and CRFD measured during the SJ demonstrated the highest amount of variability; (b) CMJ variables showed excellent reliability in endurance-trained masters cyclists with PF, PF·BM^{-1} and CRFD again being the most reliable variables, and PP, PP·BM^{-1} and CRFD again demonstrating the highest amount of variability; (c) The TEM for the six SJ variables measured ranged between 4.7% to 28.4%, with PF and PF·BM^{-1} demonstrating the lowest TEM; (d) The TEM for the five CMJ variables measured ranged between 5.4% to 17.7%, with PP·BM^{-1} demonstrating the lowest TEM.

The results of the current study demonstrate that variability in SJ and CMJ performance in masters cyclists is greater than those reported in younger athletes. In the current study CV for CMJ PF and PP was 17.3% and 5.6%, respectively. In younger athletes, much lower CV for CMJ variables has been reported [16,28]. For example, Cormack et al. [16] reported CMJ PP, PP·BM^{-1}, PF and PF·BM^{-1} to have CV of 2-3% in younger Australian Rules Football Players (23 ± 3.8 years). In addition, Hori et al. [28] reported CMJ PP and PF CV values of 1.3%-4.1% in recreationally-active, younger males (25 ± 4.4 years). However, indices for reliability in squat jump performance in younger athletes is inconsistent. For example, Cronin et al. [29] reported the CV for squat jump PF was 11.8% in a group of younger male (23.4 ± 3.6 years) athletes. Other researchers [28] have reported SJ PP CV values of 3.6% in younger athletes. In the current study squat jump PF CV was 3.9% which is similar to the values reported by Viitasalo [30] and lower than the values reported by Cronin, Hing, McNair [29]. However, in the Cronin, Hing, McNair [29] study, SJ was measured via linear force transducer, making a true comparison difficult. Taken together, these results suggest variability in the measurement of CMJ variables in endurance trained masters athletes may be greater than in younger athletes. However, the variability of SJ performance variables in both younger and endurance-trained masters athletes may be similar.

Although there is a multitude of research in younger athletes, the reliability of CMJ performance in older adults has received little attention [15,17]. Previously, Holsgaard Larsen, Caserotti, Puggaard, Aagaard [17] reported CMJ PP·BM^{-1}, PF·BM^{-1} CV of 2.9% and 5.0%, in a group of moderately-trained older women (72.3 ± 6.6 years) who were participating in multi-component activities (strength, endurance, postural control and reactive exercises) once per week. More recently, Ditroilo et al. [15] reported inter-session CMJ PP·BM^{1}and PF·BM^{-1} CV values of 2.9% and 4.1% in a group of sedentary, middle-aged (55-65 years) and older (66-75 years) men. These CV results are in contrast to the findings of the current study which showed higher CV values for CMJ PP·BM^{-1} (9.5%) and lower CV values for PF·BM^{-1} (3.9%). Age-related changes to the neuromuscular system may be largely responsible for the variation in CMJ PP observed in the current study. For example, it has been shown the ability of the neuromuscular system to optimize CMJ performance decreases with age [19]. Moreover, it has also been reported that older adults must reorganize their joint coordination while performing a CMJ, exhibiting a simultaneous coordination of body segments, compared with sequential patterns observed in younger adults [19]. Finally, Holsgaard et al. [17] has reported older adults show greater difficulty performing multi-joint motor tasks than younger adults. Therefore it is reasoned that these age-related changes contributed to the higher variation in CMJ PP and PP·BM^{-1} observed in the current study.

To date, no studies have investigated the reliability of SJ performance in healthy older adults or masters athletes. Therefore, the findings of the current study are the first to report on SJ reliability in masters athletes. The SJ reliability variables found in the current study demonstrate higher SJ CV values for PF and $PF \cdot BM^{-1}$, and lower CV values for PP and $PP \cdot BM^{-1}$. Interestingly, we observed the CV values for SJ PP and $PP \cdot BM^{-1}$ were lower than CMJ PP and $PP \cdot BM^{-1}$. As previously mentioned, age-related changes to the neuromuscular system affect CMJ performance, where there is a greater reliance on the stretch shortening cycle. The SJ in contrast, does not rely on the stretch shortening cycle or other neuromuscular factors associated with jumping performance, which may explain the results of the current study, which observed higher variability in CMJ PP than SJ PP. Taken together, these results strongly suggest SJ may be a more reliable method to assess PP in endurance-trained masters cyclists.

The RFD is the development of maximal force in minimal time, and has been shown to be an important performance variable for athletic performance [31,32]. The results of the current study found poor reliability of RFD during both the SJ (CV 27.5%) and CMJ (CV 12.2%). The poor reliability of CRFD data during the present study is consistent with reliability studies conducted in younger athletes [31,33]. For instance, McLellan et al.[31] reported the CV for RFD during the CMJ was 16.3% and 14.8% for SJ in a group of recreationally active, younger men (23 ± 3.9 years). Similarly, Moir et al.[33] reported CV% for RFD in the SJ of 12.7% in a group of recreationally active, younger men (25 ± 3.9 years). In the current study, CV values for SJ and CMJ CRFD were 12.2% and 27.5%, respectively. These CV values are lower than the values reported by McLellan et al.[31] for CMJ, but higher than the values reported by both McLellan et al.[31] and Moir et al.[33] for SJ.

To date, no other studies have reported reliability indices for RFD during CMJ or SJ tests in sedentary, older adults or masters athletes. The large variability in the reliability indices found in SJ and CMJ CRFD may be caused by the inclusion of subjects with no previous training in explosive exercise, and a longstanding history of endurance cycling training. Research suggests the training status of an individual largely determines the ability to reach PF quickly, and explosively trained athletes have been shown to reach PF more quickly than non-explosively trained subjects [32]. Moreover, Izquierdo et al.[35] has suggested long term endurance cycling may interfere with the development of muscular power in younger athletes. The subjects who participated in this study had a long history of endurance cycling training, and were untrained in either resistance or explosive exercise training. Thus, the high variability in both SJ and CMJ CRFD performance observed in the present study, may be as a result of both a lack of explosive training and a longstanding history of endurance cycling.

4.6 Conclusions

This is the first study to report a comprehensive assessment of performance variables in both SJ and CMJ in endurance-trained masters athletes. We have demonstrated that SJ and CMJ variables possess high test-retest reliability; however, in endurance-trained masters cyclists, PF may be more reliably measured using the CMJ test, whereas PP may be more reliably assessed using the SJ test. Thus, coaches and sports scientists should be cautious when selecting either the SJ or CMJ test to assess PP and PF.

The results of the present study suggest both SJ and CMJ are reliable methods to determine PP and PF capabilities in endurance-trained masters cyclists. The TEM values presented in the current study also provide both researchers and practitioners with the opportunity to determine if a training intervention has brought about a true change in either SJ or CMJ performance.

4.7 References

1. Cronin J.B, Hansen K.T (2005). Strength and power predictors of sports speed. J Strength Cond Res 19: 349-357.

2. Sleivert G, Taingahue M (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. Eur J Appl Physiol 91: 46-52.

3. Tanner R, Gore C (2013). Physiological tests for elite athletes.Canberra, Australia: Human Kinetics.

4. Bosco C, Luhtanen P, Komi P.V (1983). A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol 50: 273-282.

5. Maulder P, Cronin J (2005). Horizontal and vertical jump assessment: Reliability, symmetry, discriminative and predictive ability. Phys Ther Sport 6: 74-82.

6. Forte R, Macaluso A (2008). Relationship between performance-based and laboratory tests for lower-limb muscle strength and power assessment in healthy older women. J Sports Sci 26: 1431-1436.

7. Edwén C, Thorlund J.B, Magnusson S.P (2014). Stretch-shortening cycle muscle power in women and men aged 18–81 years: Influence of age and gender. Scand J Med Sci Sports 24: 717-726.

8. Häkkinen K, Kraemer W, Newton R, Alen M (2001). Changes in electromyographic activity, muscle fibre and force production characteristics during heavy resistance/power strength training in middle-aged and older men and women. Acta Physiol Scand 171: 51-62.

9. Häkkinen K, Kallinen M, Izquierdo M (1998). Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. J App Physiol 84: 1341-1349.

10. Kalapotharakos V, Tokmakidis S, Smilios I, Michalopoulos M (2005). Resistance training in older women: Effect on vertical jump and functional performance. J Sports Med Phys Fit 45: 570-575.

11. Reaburn P, Dascombe B (2008). Endurance performance in masters athletes. Eur Rev Aging Phys Act 5: 31-42.

12. Michaelis I, Kwiet A, Gast U (2008). Decline of specific peak jumping power with age in master runners. J Musculoskelet Neuronal Interact 8: 64-70.

13. Rittweger J, Kwiet A, Felsenberg D (2004). Physical performance in aging elite athletes – challenging the limits of physiology. J Musculoskelet Neuronal Interact 2: 159-160.

14. Grassi B, Cerretelli P, Narici M, Marconi C (1991). Peak anaerobic power in master athletes. Eur J Appl Physiol Occup Physiol 62: 394-399.

15. Ditroilo M, Forte R, McKeown D, Boreham C, De Vito G (2011). Intra-and inter-session reliability of vertical jump performance in healthy middle-aged and older men and women. J Sports Sci 29: 1675-1682.

16. Cormack S.J, Newton R.U, McGuigan M.R, Doyle T.L (2008). Reliability of measures obtained during single and repeated countermovement jumps. Int J Sports Physiol Perform 3: 131.

17. Holsgaard Larsen A, Caserotti P, Puggaard L, Aagaard P (2007). Reproducibility and relationship of single-joint strength vs multi-joint strength and power in aging individuals. Scand J Med Sci Sports 17: 43-53.

18. Rittweger J, Schiessl H, Felsenberg D, Runge M. (2004). Reproducibility of the jumping mechanography as a test of mechanical power output in physically competent adult and elderly subjects. J Am Geriatr Soc 52: 28-131.

19. Haguenauer M, Legreneur P, Monteil K.M (2005). Vertical jumping reorganization with aging: A kinematic comparison between young and elderly men. J Appl Biomech. 21: 236-246.

20. Liu Y, Peng C-H, Wei S-H, Chi J-C, Tsai F-R, Chen J-Y (2006). Active leg stiffness and energy stored in the muscles during a maximal counter movement jump in the aged. J Electromyogr Kinesiol 16: 342-351.

21. Samozino P, Morin J-B, Hintzy F, Belli A (2008). A simple method for measuring force, velocity and power output during a squat jump. J Biomech 41: 2940-2945.

22. Goto, R., & Mascie-Taylor, C. N. (2007). Precision of measurement as a component of human variation. J Physiol Anthropol. 26: 253-256

23. Ulijaszek, S. J., & Kerr, D. A (1999). Anthropometric measurement error and the assessment of nutritional status. Br J Nutr 82(03), 165-177.

24. Driller M.W, Argus C.K, Shing C.M (2012). The reliability of a 30 second sprint test on the wattbike cycle ergometer. Int J Sports Physiol Perform 8: 379-383.

25. Hopkins W.G, Schabort EJ, Hawley JA. (2001). Reliability of power in physical performance tests. Sports Med 31: 211-234.

26. Hopkins W.G (2009). Calculating the reliability intraclass correlation coefficient and its confidence limits (excel spreadsheet). www.sportsci.org/resource/stats/xICC.xls Accessed: 3rd March 2016.

27. Sattler T, Sekulic D, Hadzic V, Uljevic O, Dervisevic E. (2012). Vertical jumping tests in volleyball: Reliability, validity, and playing-position specifics. J Strength Cond Res 26: 1532-1538.

28. Hori N, Newton R.U, Kawamori N, McGuigan MR, Kraemer W.J, Nosaka K (2009). Reliability of performance measurements derived from ground reaction force data during a countermovement jump and the influence of sampling frequency. J Strength Cond Res 23: 874-882.

29. Cronin J.B, Hing R.D, McNair P.J (2004). Reliability and validity of a linear position transducer for measuring jump performance. J Strength Cond Res 18: 590-593.

30. Viitasalo J.T (1998). Evaluation of explosive strength for young and adult athletes. Res Q Exerc Sport 59:9-13.

31. McLellan C.P, Lovell D.I, Gass G.C (2001). The role of rate of force development on vertical jump performance. J Strength Cond Res 25: 379-385.

32. Cronin J.B, Sleivert G (2004). Challenges in understanding the influence of maximal power training on improving athletic performance. Sports Med. 2004;35:213-234.

33. Moir G, Sanders R, Button C, Glaister M (2005). The influence of familiarization on the reliability of force variables measured during unloaded and loaded vertical jumps. J Strength Cond Res 19: 140-145.

34. Young W.B, Bilby G.E (1993). The effect of voluntary effort to influence speed of contraction on strength muscular power, and hypertrophy development. J Strength Cond Res 7: 172-178.

35. Izquierdo M, Ibáñez J, Häkkinen K, Kraemer WJ, Ruesta M, Gorostiaga E.M (2004). Maximal strength and power, muscle mass, endurance and serum hormones in weightlifters and road cyclists. J Sports Sci 22: 465-478.

5

Manuscript 4 –

Health Benefits of Concurrent Resistance and Sprint Cycling Training

This chapter is presented with the text formatting and referencing styles required by the *Journal of Exercise Rehabilitation*.

Declaration of Co-Authorship and Contribution

Title of Paper	Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists
Full bibliographic reference for Journal/Book in which the Paper appears	**Del Vecchio**, L., Reaburn, P., Trapp, G., Korhonen, M.T. (2016). Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists. *Journal of Exercise Rehabilitation*, 12(5): 442-450
Status	Published

Nature of Candidate's Contribution

Luke Del Vecchio conceived the research idea, designed the experiment, collected data, , statistically analysed the data, drafted manuscript in full, edited the manuscript based on co-author feedback, submitted the manuscript, and responded to reviewer comments.

Nature of Co-Authors' Contributions

Peter Reaburn and Marko Korhonen refined the experimental design, reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Nattai R. Borges reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Please Note the reference format in the following paper is "as per the journals required referencing format".

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Publication of Research Higher Degree Work for Inclusion in the Thesis Procedures.

Signature:

Date: 20th June 2016

Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists

5.1 Abstract

In older previously sedentary individuals, endurance training imposes a more effective stimulus to enhance cardiometabolic health compared with resistance or sprint training. We examined the effect of replacing a portion of endurance training with combined resistance and/or sprint training and how this influences cardiometabolic health indicators in masters endurance cyclists. Twenty seven well-trained male road cyclists (53.7 ± 8.2 years) were allocated to a resistance and track sprint cycling training group (RTC, n=10), an endurance and track sprint-cycling group (ETC, n=7) or a control endurance group (CTRL, n=10). Both the RTC and ETC group completed a 12-week intervention of specific training while the CTRL group maintained their endurance training load. Lower limb lean mass (LLM), trunk fat mass (TFM), fasting blood glucose (FBG), total cholesterol (T-C), triglycerides (TG), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured before and after the intervention period. The Trunk Fat Mass decreased for all groups ($p<0.05$) while LLM significantly increased for RTC and ETC groups ($p<0.05$). No significant between group or time effects were observed for FBG, T-C, TG, SBP or DBP. The results suggest that replacing a portion of endurance training with 12-weeks of ETC or RTC training favourably affects body composition by lowering TFM and increasing LLM without negatively affecting cardiometabolic health indicators in well-trained masters endurance cyclists.

Key Words: aging, resistance training, cycling, blood pressure, blood lipids

5.2 Introduction

Normal aging is typically associated with unfavourable changes in serum lipids and blood pressure levels, both of which increase the risk of cardiometabolic diseases such as atherosclerotic vascular disease and type 2 diabetes (Buitrago-Lopez et al., 2011). However, these negative changes in the metabolic profile are determined not only by biological aging itself but also lifestyle factors such as lack of exercise and a poor diet (Gaesser, Angadi, & Sawyer, 2011).

Previous studies suggests that resting blood pressure of middle-aged and older endurance runners are at optimal levels (≤120/80 mmHg) and lower than in both age-matched strength and sprint athletes (Kusy & Zielinski, 2015) and inactive controls (Buyukyazi, 2005; Cornelissen et al., 2009; Hernelahti et al., 2002). Moreover, previous studies have shown lower blood glucose, total cholesterol and triglyceride levels in older endurance-trained athletes than age-matched non-athletic controls (Mikkelsen et al., 2013). Taken together, these data suggest endurance training may explain the lower blood pressure and blood lipid levels observed in older endurance athletes.

Despite the widely known performance and cardiometabolic benefits of endurance training, previous research has reported masters athletes involved in non-weight-bearing endurance sports such as cycling and swimming have lower bone mineral density compared with other athletes and even non-active controls (Nichols, Palmer, & Levy, 2003; Rector et al., 2008). As a result of these findings, masters endurance cyclists may need to incorporate resistance training into their endurance training regimes to maintain optimal bone density as they age (Bolam et al., 2015; Hinton, Nigh, & Thyfault, 2015). In addition to resistance training, many road cyclists also incorporate high intensity sprint training to further improve road cycle-racing performance where ‘attacks’ during a road race and sprint finishes are major factors in successful road cycle-racing. However, it is possible that replacing a portion of endurance training with strength or sprint training may lead to a reduction in endurance training volume which may negatively effect the cardiometabolic profile of masters road cyclists. Indeed, previous research has shown that reductions in endurance training volume lead to increased cardiometabolic risk in both younger runners (Sutherland, Woodhouse, Williamson, & Smith, 1981) and masters cyclists (Giada et al., 1995). In contrast, recent evidence suggests that positive metabolic and musculoskeletal adaptations in healthy older adults occur from short-term resistance and sprint training if the intensity of that training is high (Bell et al., 2015; Nederveen et al., 2015). Therefore, the purpose of this study was to determine if replacing a portion of endurance training with combined resistance and sprint training or sprint training alone will negatively affect cardiometabolic health indicators in masters endurance cyclists.

5.3 Methods

5.3.1 Participants

The study was approved by the Central Queensland University Human Research Ethics Committee. Twenty seven male masters endurance cyclists (53.7 ± 8.2 years) with no background of resistance training were recruited and provided written informed consent. The subjects were required to be involved in regular cycling training and competition for a minimum of two years and to be achieving a minimum of eight hours of endurance cycling training per week. All subjects underwent pre-exercise screening to ensure they had no established cardiovascular, metabolic or respiratory disease (nor) signs (or) symptoms of these conditions (Norton, 2005).

Random allocation of participants into training groups was not possible as a result of the majority of participants having both work and family commitments that limited their availability to participate in the RTC or ETC training programs. As a result, subjects were allocated to either a control group (CTRL, n=10), an endurance and track sprint-cycling group (ETC, n=7) or resistance and track sprint-cycling training group (RTC, n=10) based on their availability. Participants were encouraged and agreed to avoid changes in their diet or lifestyle over the intervention period. The physical characteristics of each group are shown in Table 5.1.

Table 5.1. Physical characteristics and training hours per week of the groups

	Resistance & Track Sprint-cycling Group (n=10)	**Track Sprint-cycling Group (n=7)**	**Control Group (n=10)**
Age (years)	53.5 ± 9.3	49.4 ± 4.8	56.9 ± 8.6
Stature (m)	1.80 ± 0.1	1.80 ± 0.1	1.75 ± 0.1
Body mass (kg)	81.9 ± 6.1	78.5 ± 6.1	83.5 ± 10.0
Training hours (hr/week)	8.2 ± 1.0	8.1 ± 1.3	8.0 ± 1.2

Data are Mean ± SD

5.3.2 Protocol

Subjects attended the laboratory following an overnight fast and did not consume caffeine on the morning of the testing sessions carried out between 07:00 and 09:00 hours. Pre- and post-intervention testing included, which were: anthropometric measures, Dual Energy X-Ray Absorptiometry (DEXA), fasting blood glucose, fasting blood lipids, resting blood pressure and determination of VO_{2peak} on a cycle ergometer. All measurements were performed by the same trained observer.

5.3.3 Anthropometry measures

Stature (m) and body mass (kg) were measured with a stadiometer and medical scales (Seca, Birmingham, UK) with participant’s unshod and wearing cycling apparel.

5.3.4 DEXA scanning

DEXA (Hologic Discovery-W, Bedford, MA.) was used to measure trunk fat mass (TFM) and lower limb lean mass (LLM). A single trained DEXA technician performed all DEXA measurements. The trunk region consists of the area bordered by a horizontal line below the chin, vertical borders lateral to the ribs and oblique lines passing through the femoral necks. The leg region includes all tissue below these oblique lines.

5.3.5 Blood measures

Subjects were required to fast for eight hours prior to the blood tests. Fasting blood glucose (FBG), total cholesterol (T-C) and triglycerides (TG) were measured via a 30µl capillarized blood sample taken from each subject's fingertips. For the analysis of FBG, T-C and TG a sample of whole blood was collected into a capillary pipette and applied to the Reflotron reagent strip (Roche Diagnostics, Sydney, Australia). Blood samples were processed using a Reflotron Plus reflectance photometer (Hoffman La Roche ltd, Basel, Switzerland). Coefficient of variation for FBG is 2.5%, T-C is 1.2% and TG is 2.9% (Roche Diagnostics, Sydney, Australia).

5.3.6 Resting blood pressure

Resting blood pressure was measured upon arrival at the laboratory and after the subjects had undertaken ten minutes of seated rest in quiet and comfortable conditions. Blood pressure was measured using a standard mercury hand held sphygmomanometer (Nova-Presameter, Riester, Jungingen, Germany) using the standard guidelines established by the American Heart Association (Perloff et al., 1993). Blood pressure was obtained in triplicate for both arms and each measurement was separated from the next by a 1-2 minute resting period. The blood pressure obtained from the arm with the highest reading was used for statistical analysis.

5.3.7 Vo_{2peak}

A graded maximal exercise test to measure peak aerobic power (VO_{2peak}) was completed on an electrically-braked, computer controlled cycle ergometer (Velotron Dynafit Pro, RaceMate, Seattle, WA, USA). Gas analysis was undertaken using a *Fitmate Pro* (Cosmed, Rome, Italy) (Brisswalter & Tartaruga, 2014) following a 5-minute warm-up at 30 W cycling and a pedalling cadence of 90 rpm throughout the test. The work increments for each one-minute stage were 15 W. The test ceased when no significant increase in O_2 uptake with an increase in work rate occurred and/or at volitional exhaustion (Schell & Leelarthaepin, 1990). The test was followed by a 5-min cool down at a self-selected intensity and cadence.

5.3.8 Endurance and Track Sprint-Cycling Program

Both RTC and ETC groups replaced two of their usual weekly endurance cycling training sessions with two group track-cycling sessions per week, lasting approximately 90 minutes and separated by 48 hours. The sprint cycling program was performed in the evening at an outdoor cycling velodrome. The training program was designed in consultation with an accredited track cycling coach and supervised by the same coach for each session. The sprint cycling training sessions consisted of a five to ten minute warm-up of 10-15 laps at a self-selected pace after which subjects performed 1-3 sets x 1-3 repetitions of maximal effort sprints ranging in distance from 65 meters to 330 meters (sprint times ranged from 6 to 30 seconds) with 2-3 mins of active recovery between repetitions and 10-15 mins passive rest between sets. At the completion of the track training session subjects performed a 5-

10 minute cool down of 10-15 laps of the velodrome at a self-selected pace. Selected strategies to achieve increased maximum speed and acceleration capabilities included ‘Over Gear Training’ with a gear that is larger than the athlete’s typical race gear. Furthermore, the sprint cycling program also incorporated an ascending progressive gear overload method where the gearing size increased progressively following each individual sprint. The overall training adherence rate calculated as a percentage of the total training sessions successfully completed was 87 ± 4% for all sprint cycling training across the 12-week study period with no differences between the RTC and ETC groups.

5.3.9 Resistance Training and Track Sprint-Cycling Program

The RTC group replaced four of their usual weekly endurance cycling training sessions with two evening group track sprint-cycling training sessions as described above, and two morning gym-based group resistance training sessions per week. All four training sessions were supervised by a certified strength and conditioning coach. Resistance training sessions were conducted on alternate days to the track sprint training days. During each resistance training session participants completed exercises in the following order: double- and single-leg hopping (2-3 sets of 10-20 hops), box jumps, leg press throws, single-leg leg presses, seated hip flexions, leg curls, leg extensions, seated calf-raises, supine hip extensions, chest presses, bench rows, abdominal curl ups and lower back extensions. Recovery time of two minutes between sets and exercises was strictly controlled with the resistance training sessions lasting approximately 90 minutes. The progressive resistance training program was periodised to reduce both the potential for overtraining and to optimise neuromuscular adaptation. Subjects completed electronic training logs describing all their training parameters (number of repetitions, sets, loads, track and road training distances, track sprint cycling times) to monitor progress and to provide motivation for maximal effort during the training program. The overall training adherence rate, calculated as a percentage of training sessions successfully completed was 85 ± 4% for track sprint-cycling training and 82 ± 5% for resistance training across the 12-week study period.

5.3.10 Control group

The CTRL group were asked to maintain 8 hours per week of endurance cycling training for the 12-weeks intervention period.

5.3.11 Statistical analysis

A three (ETC, RTC, CTRL) x two (pre, post) repeated measures analysis of variance (ANOVA) was used to contrast dependent variables of interest. If a main effect was observed, a Tukey post-hoc test was undertaken to identify the source of the differences. A p value of <0.05 was considered to be statistically significant. Cohen's conventions for effect size (ES) were used for interpretation where ES = 0.2, 0.5 and 0.8 are considered as small, medium and large, respectively (Cohen, 2013). SPSS Version 20 (IBM, Corp, New York) software was used for all statistical analyses.

5.4 Results

Table 5.2 shows the changes in each of the variables of interest for each of the groups over the 12-week intervention period.

Table 5.2. DEXA, fasting blood glucose, blood lipids and VO_{2peak} changes in RTC, ETC and CTRL groups following the 12-week training intervention.

	Resistance & Track-Cycling Group (n=10)			**Track-Cycling Only Group (n=7)**			**Control Group (n=10)**		
	Pre	**Post**	***Change***	**Pre**	**Post**	***Change***	**Pre**	**Post**	**change**
TFM (kg)	7.7 ± 2.7	7.3 ± 2.1	-5.1%	6.7 ± 1.1	6.0 ± 0.9	-10.4%	8.7 ± 1.1	8.5 ± 1.3	-2.2%
LLM (kg)	17.4 ± 1.8	18.0 ± 2.3†	3.4%	17.0 ± 1.5	17.6 ± 1.4†	3.5%	16.0 ± 2.0	16.0 ± 1.9	0.0%
FBG (mmol/l)	5.1 ± 0.3	5.0 ± 1.2	-2.7%	5.3 ± 0.7	4.64 ± 0.9	-12.6%	5.1 ± 0.6	5.2 ± 0.8	0.7%
T-C (mmol/l)	4.2 ± 1.0	3.9 ± 1.1 .	-7.1%	4.7 ± 0.7	4.2 ± 1.2	-10.6%	4.8 ± 1.1	4.5 ± 1.6	-6.25%
TG (mmol/l)	0.92 ± 0.2	0.90 ± 0.25	-2.2%	1.2 ± 0.4	1.0 ± 0.5	-16.7%	1.9 ± 1.8	1.6 ± 0.60	-15.8%
SBP (mm Hg)	122 ± 5.9	119 ± 6.5	-2.4%	129 ± 9.0	121 ± 9.3	-6.2%	136 ± 12.2	138 ± 21.8	1.5%
DBP (mm Hg)	79 ± 5.5	78 ± 6.5	-1.2%	80 ± 4.1	78 ± 6.9	-2.5%	87 ± 7.2	88 ± 5.8	1.1%
$VO_{2\,peak}$ (ml/kg/min)	46.7 ± 9.3	45.6 ± 8.4	-2.3%	54.0 ± 10.2‡	51.9 ± 7.1	-3.9%	36.9 ± 9.2‡	38.4 ± 6.9	1.0%

Values are mean ± SD; † = Significant pre to post effect ($P < 0.05$); ‡ = significant difference between ETC and control group ($P < 0.05$). Change = percentage change from pre to post training; LLM = lower limb lean mass; TFM = trunk fat mass; FBG = fasting blood glucose; T-C = total cholesterol; TG = triglycerides; SBP = systolic blood pressure; DBP = diastolic blood pressure; $V0_{2\,peak}$ = peak aerobic power; RTC = resistance and track-cycling group; ETC = endurance and track-cycling group; CTRL = control group.

5.4.1 Trunk fat mass

A significant effect of time was observed for TFM ($p<0.01$). However, no significant between group effects were observed for TFM ($p=0.49$) following the exercise training period. Effect size analysis revealed that 12-weeks of RTC training had no effect on TFM in the RTC group (ES=-0.16) or CTRL group (ES=-0.16). However, 12-weeks of ETC training had a moderate, negative effect on TFM in the ETC group (ES=-0.69). There was no effect on TFM following the exercise training period observed in the control group (ES=-0.16).

5.4.2 Lower limb lean mass

Lower limb lean mass increased significantly in both the RTC group ($p = 0.01$) and the ETC group ($p = 0.01$) with no significant between-group differences observed for LLM ($p = 0.89$). 12-weeks of RTC training had a small effect on LLM in the RTC group (ES = 0.29). In contrast, 12-weeks of ETC training had a moderate effect on LLM in the ETC group (ES = 0.41). There was no effect on LLM following the exercise training period observed in the CTRL group (ES = 0.00).

5.4.3 Fasting blood glucose

There were no significant effects of time ($p=0.35$) or between group differences observed for FBG ($p=0.46$) following the study intervention period. Effect size analysis revealed RTC training had no effect on FBG (ES = -0.16). In contrast, 12-weeks of ETC training had a large effect (ES = -0.83) on FBG in the ETC group. There was no effect on FBG following the exercise training period observed in the control CTRL group (ES = -0.05).

5.4.4 Total cholesterol

There were no significant effects of time (p=0.06) or between group differences (p=0.82) observed for T-C following the intervention. Effect size analysis revealed 12-weeks of RTC training had a small effect on T-C (ES = -0.30). In contrast, 12-weeks of ETC training had a moderate effect on T-C (ES = -0.40). There was a small effect on T-C following the exercise training period observed in the control group CTRL (ES = -0.21).

5.4.5 Triglycerides

There were no significant effects of time (p=0.51) or between group differences (p=0.22) observed for TG following the study period. Effect size analysis revealed 12-weeks of RTC training had no effect on TG (ES = -0.08). In contrast, 12-weeks of ETC had a small effect on TG (ES = -0.30). There was a small effect on TG following the exercise training period observed in the CTRL group (ES = -0.22).

5.4.6 Blood pressure

There were no significant effects of time (p = 0.34) or between group differences (p=0.28) observed for SBP following the study period. Effect size analysis revealed 12-weeks of RTC training had a moderate effect on SBP (ES = -0.48). In contrast, 12-weeks of ETC had a large effect on SBP (ES = -0.87). There was no effect on SBP following the exercise training period observed in the control CTRL group (ES = 0.11).

There were also no significant effects of time (p=0.32) or between group differences (p=0.43) observed for DBP following the study period. Effect size analysis revealed 12-weeks of RTC training had no effect on DBP (ES = -0.16). In contrast, 12-weeks of ETC training had a small effect on DBP (ES = -0.36). There was no effect on DBP following the exercise training period observed in the control CTRL group (ES = 0.15).

5.4.7 V0$_{2peak}$

There was a significant between group difference in pre $VO_{2\ peak}$ (p= 0.01). It was significantly greater in the ETC, compared to the CTRL group (p=0.01) (Table 2). There were no significant effects of time (p=0.73) or between group differences (p=0.60) observed for VO_{2peak} following the training period. Effect size analysis revealed RTC training had no effect on VO_{2peak} (ES = -0.12). In contrast, 12-weeks of ETC training had a small effect on VO_{2peak} (ES = -0.23).There was no effect on VO_{2peak} following the exercise training period observed in the CTRL group (ES = 0.18).

5.5 Discussion

Recent evidence suggests that short-duration sprint and/or resistance training may lead to positive adaptations in cardiometabolic risk factors if the intensity of exercise is high (Bell et al., 2015; Kusy & Zielinski, 2015). This evidence supports the long held position that endurance training leads to significant improvements in the cardiometabolic risk profile in previously sedentary older individuals. In the present study we investigated whether the replacement of a portion of endurance training by resistance and sprint exercise might influence body composition and cardiometabolic health indicators in endurance-trained masters cyclists. The major finding of the present study was that TFM was significantly reduced in both the ETC and RTC groups. Moreover, 12 weeks of RTC and ETC significantly increased LLM. However, there were no significant changes or between group differences in the important cardiometabolic health indicators of FBG, T-C, TG, SBP or DBP. Therefore, the current data supports the hypothesis that 12-weeks of RTC or ETC will not negatively affect cardiometabolic health indicators in masters endurance cyclists.

Trunk fat mass is a well-recognised and independent risk factor for cardiometabolic disease (Hu et al., 2011). Thus, the significant reduction in TFM observed in the ETC and RTC groups of the present study suggest the addition of high intensity sprint and/or resistance training may lower the risk of cardiometabolic disease in endurance-trained masters cyclists. Indeed, in the present study, 12-weeks of ETC reduced TFM by 10.4% accompanied by a moderate effect size (-0.69). Moreover, the RTC group reduced TFM by 5.1% (-0.16) while the CTRL group reduced TFM by 2.2% (-0.16). These findings are in agreement with earlier findings by Treuth et al. (1994) who reported a significant reduction in TFM following 16 weeks of resistance training performed three times per week in a group of healthy, older males aged 50-75 years. More recently, Sillanpää et al. (2009) also reported a significant reduction in TFM following 21 weeks of combined resistance and endurance training performed four times per week in a group of middle-aged females aged 48.9 ± 6.8 years. However, our study is the first to have investigated the effects of resistance and/or sprint training on TFM in healthy older adults who are also masters athletes. Taken together, the present and previous results suggest ETC training may be more beneficial for reducing TFM than RTC or endurance cycling training alone in masters endurance cyclists.

The present study also observed a significant increase in LLM following 12-weeks of RTC and ETC training. These findings are in agreement with previous studies that have reported significant increases in lean mass in response to a combined resistance and sprint training intervention in masters sprint runners (Cristea et al., 2008; Reaburn, Logan, & Mackinnon, 1994). For example, Cristea et al. reported a significant increase in LLM in a group of sprint-trained male masters sprint runners who completed a 20 week progressive resistance training program. The loss of muscle mass with age is an independent risk factor for cardiometabolic disease (Dominguez & Barbagallo, 2007). Masters athletes, like their sedentary age-matched counterparts are susceptible to an age-related decline in muscle mass (Reaburn & Dascombe, 2009) which may thus increase their risk of cardiometabolic disease. In the present study, RTC training had a small effect on LLM in the RTC group with a moderate effect on LLM observed in the ETC group. Recent research suggests sprint training may positively affect lean mass in healthy but previously untrained older adults (Bell et al., 2015; Nederveen et al., 2015).Taken together with these previous findings, the present data suggest sprint training may induce muscle hypertrophy in masters athletes which subsequently may reduce the risk for cardiometabolic disease. Moreover, the present findings suggest the increased muscle hypertrophy produced by augmenting endurance training with sprint or resistance training does not appear to negatively impact on important cardiometabolic risk factors.

In the present study we also examined the effects of 12-weeks of ETC and RTC training on a number of commonly measured cardiometabolic risk factors including FBG, T-C, TG SPB and DBP. In summary, the current data suggests RTC and ETC had no negative effect on any of the cardiometabolic risk factors when an older endurance athlete has a significant volume of their endurance training replaced by either sprint training alone or concurrent sprint and resistance training.

Hyperglycaemia is a widely acknowledged risk factor for cardiometabolic disease (Brunzell et al., 2008). The present study observed that 12-weeks of RTC or ETC did not negatively affect FBG levels in masters endurance cyclists who replaced a significant portion of their normal endurance training with sprint and/or resistance training. These data are in agreement with similar studies that have observed no effect of resistance training on FBG in healthy older adults (Ferrara et al., 2004; Zachwieja et al., 1996). In the present study, 12-weeks of ETC non-significantly reduced FBG by 12.6% but was accompanied by a large effect size (-0.83) in the ETC group. Previous research examining the effect of sprint and endurance training in masters athletes suggests that long-term sprint training may not have a favourable effect on glucose metabolism (Kusy & Zielinski, 2015; Kusy et al., 2013). Importantly, the FBG of both the RTC and ETC groups were within the acceptable range for FBG (World Health Organization, 2006) suggesting that RTC and ETC training maintains FBG within healthy ranges. Taken together, the results of the current study suggest that 12-weeks of RTC or ETC does not negatively affect FBG in masters endurance cyclists who replace part of their normal endurance training with sprint-only or concurrent sprint and resistance training.

Elevated T-C increases the risk for cardiometabolic disease, particularly with age (Campesi et al., 2016).The present study is the first to examine the effect of ETC and RTC on T-C in masters athletes. We observed that 12-weeks of ETC or RTC did not negatively affect T-C levels in masters endurance cyclists who lowered their endurance training volume to accommodate the ETC or RTC training. These findings are consistent with previous studies examining the effect of sprint cycling training on blood lipids in overweight and previously sedentary middle-aged men (Moreira et al., 2008; Wallman et al., 2009). Previous research has also shown that masters athletes (45.9 ± 4.8 years) who regularly participate in field sports such as soccer or hockey had significantly lower T-C levels than age-matched sedentary controls (Dey et al., 2002). These data suggest that sports which involve repeated powerful muscular actions and sprinting may exert a positive effect on T-C in masters athletes. The findings of the present study support this suggestion with a 10.6% reduction in T-C following 12-weeks of track sprint cycling training. Taken together, this data suggests reducing replacing a portion of endurance training with track-sprint training does not negatively affect T-C in masters endurance cyclists.

In the present study, T-C was reduced by 7.1% within the RTC group, but these changes were not significant. However, the reductions in T-C observed in the present study may be clinically relevant since as little as a one percent reduction in T-C has been shown to be associated with a two to three percentage point reduction in the incidence of coronary heart disease (Law, Wald, & Thompson, 1994). Therefore, our data suggests both ETC and RTC training may be used by older populations to lower T-C and impact on cardiometabolic health. To date, no research has investigated the effects of resistance training on T-C in masters athletes. The present findings are in agreement with previous research which has shown in untrained older men, high intensity resistance training favourably effects T-C levels (Hagerman et al., 2000; Joseph et al., 1999; Leenders et al., 2013). In addition, previous research (Martins et al., 2010) has reported moderate to high intensity resistance training also induces favourable changes in T-C in healthy older males (76 ± 8.0 years). Taken together, these results again suggest T-C is not negatively influenced by RTC training in masters endurance cyclists.

Elevated triglycerides are an independent risk factor for cardiometabolic disease (Pirillo, Norata, & Catapano, 2014). In the current study, 12-weeks of either ETC training or RTC training had no significant effect on TG in masters endurance cyclists. These results are in agreement with previous studies that have reported no significant reduction in TG in response to high intensity sprint training in overweight, middle-aged males and females (Moreira et al., 2008) and obese middle-aged males and females (Wallman et al., 2009). Moreover, previous studies have also reported no significant reduction of resistance training alone on TG in healthy older men (Hagerman et al., 2000) and overweight older males and females (Joseph et al., 1999).

In summary, the lack of a significant affect of ETC and RTC on T-C and TG in the current study may be attributed to the following factors. First, participants in both the training groups were already well-trained endurance cyclists and thus may have already lowered their lipids, a finding commonly observed following years of endurance training

(Thompson et al., 1988; Wallman et al., 2009). Secondly, the small detraining effect on VO_{2peak} observed in the RTC and ETC groups may be partly responsible for the small changes in TC and TG. For example, Giada et al. (1995) reported an eight-week detraining period significantly increased TG and decreased HDL cholesterol in conjuction with a significant decrease in VO_{2peak} in a group of masters cyclists aged 50-65 years.

Hypertension is associated with several cardiometabolic disorders including diabetes and dyslipidaemia (Nevese et al., 2013). In the current study, 12-weeks of RTC training reduced SBP by 3.0 mmHg and DBP by 1.0 mmHg with these results accompanied by a moderate effect on SBP (-0.48) but no effect on DBP. To the best of our knowledge, no previous studies have investigated the effects of resistance training on blood pressure in masters athletes. However, previous research suggests moderate intensity resistance training has favourable effects on blood pressure in healthy older adults (Collier et al., 2008; Westcott et al., 2009). While the present changes were not statistically significant, a 5 mm Hg drop in SBP at a population level is associated with a 9% reduction in death due to CHD (Sharman & Stowasser, 2009). Thus, the current study demonstrates that RTC training may have the potential to further reduce BP and thus cardiometabolic risk in masters endurance cyclists.

The current study observed no negative effect of ETC training on SBP or DBP in masters endurance cyclists. In the present study, 12-weeks of ETC training reduced SBP by 8mm Hg and DBP by 2.2 mm.Hg non-significantly, but with these reductions complemented by a large effect on SBP (-0.87) and a moderate effect on DBP (-0.65). However, the observed non-significant reductions in SBP observed in the present study may be clinically relevant since a reduction in SBP of 3 mm Hg for normotensive individuals such as those in the present study has been shown to reduce all-cause mortality by 4% at a population level (Collier et al., 2008).

Previous observational studies have suggested that sprint training may reduce BP measures in aging athletes when comparing blood pressure values in masters track and field athletes with those from healthy, age-matched controls (Hernelahti et al., 2002; Kettunen, Kujala, Kaprio, & Sarna, 2006).Therefore, the present and previous results suggest ETC training may be used in a pre-hypertensive older population to lower BP. In summary, the results of the current study suggest replacing a portion of endurance training with either ETC alone or RTC training does not have a negative effect on both SBP and DBP in masters endurance cyclists.

Finally, in the present study, we observed a small but non-significant decrease in VO_{2peak} in the RTC group (-2.3%) and the ETC group (-3.9%). In contrast the CTRL group demonstrated a small non-significant increase (1%). However, these changes are within standard error of measurement ranges for VO_{2peak} testing both within our laboratory and Australian accredited exercise testing laboratories (Tanner & Gore, 2013). These results suggest that replacing a portion of endurance training with 12-weeks of either ETC or RTC training does not significantly reduce VO_{2peak}, despite a reduction in overall endurance training volume.

5.6 Conclusion

The results of the present study suggest that 12-weeks of ETC or RTC training favourably affects body composition by lowering TFM and increasing LLM in well-trained masters endurance cyclists. These positive changes in body composition may lower the risk for cardiometabolic disease. Moreover, the present findings suggest that cardiometabolic health indicators including FBG, T-C, TG, SBP and DBP are unaffected by a reduction in endurance training volume in masters endurance cyclists who replace part of their endurance training volume and undertake resistance and/or sprint training.

5.7 References

Bell, K. E., Séguin, C., Parise, G., Baker, S. K., & Phillips, S. M. (2015). Day-to-day changes in muscle protein synthesis in recovery from resistance, aerobic, and high-intensity interval exercise in older men. *J Gerontol A Biol Sci Med Sci, 70*(8), 1024-1029.

Bolam, K. A., Skinner, T. L., Jenkins, D. G., Galvão, D. A., & Taaffe, D. R. (2015). The osteogenic effect of impact-loading and resistance exercise on bone mineral density in middle-aged and older men: A pilot study. *Gerontology, 62*(1), 22-32.

Brisswalter, J., & Tartaruga, M. P. (2014). Comparison of COSMED'S FitMate™ and K4b2 metabolic systems reliability during graded cycling exercise. *Scand J Clin Lab Invest 74*(8), 722-724.

Brunzell, J. D., Davidson, M., Furberg, C. D., Goldberg, R. B., Howard, B. V., Stein, J. H., & Witztum, J. L. (2008). Lipoprotein management in patients with cardiometabolic risk: consensus conference report from the American Diabetes Association and the American College of Cardiology Foundation. *J Am Coll Cardiol, 51*(15), 1512-1524.

Buitrago-Lopez, A., Sanderson, J., Johnson, L., Warnakula, S., Wood, A., Di Angelantonio, E., & Franco, O. H. (2011). Chocolate consumption and cardiometabolic disorders: systematic review and meta-analysis. *BMJ, 343*, d4488.

Buyukyazi, G. (2005). Differences in blood lipids and apolipoproteins between master athletes, recreational athletes and sedentary men. *J Sports Med Phys Fitness, 45*(1), 112.

Campesi, I., Occhioni, S., Tonolo, G., Cherchi, S., Basili, S., Carru, C., Franconi, F. (2016). Ageing/menopausal status in healthy women and ageing in healthy men differently affect cardiometabolic parameters. *Int J of Med Sci, 13*(2), 124.

Cohen, J. (2013). Statistical power analysis for the behavioral sciences: Routledge Academic.

Collier, S., Kanaley, J., Carhart, R., Frechette, V., Tobin, M., Hall, A., Fernhall, B. (2008). Effect of 4 weeks of aerobic or resistance exercise training on arterial stiffness, blood flow and blood pressure in pre-and stage-1 hypertensives. *J Hum Hypertens 22*(10), 678-686.

Cornelissen, V. A., Arnout, J., Holvoet, P., & Fagard, R. H. (2009). Influence of exercise at lower and higher intensity on blood pressure and cardiovascular risk factors at older age. *J Hum Hypertens 27*(4), 753-762.

Cristea, A., Korhonen, M., Häkkinen, K., Mero, A., Alén, M., Sipilä, S., Larsson, L. (2008). Effects of combined strength and sprint training on regulation of muscle contraction at the whole-muscle and single-fibre levels in elite master sprinters. *Acta Physiol 193*(3), 275-289.

Dey, S. K., Ghosh, C., Debray, P., & Chatterjee, M. (2002). Coronary artery disease risk factors & their association with physical activity in older athletes. *J Cardiovasc Risk, 9*(6), 383-392.

Dominguez, L. J., & Barbagallo, M. (2007). The cardiometabolic syndrome and sarcopenic obesity in older persons. *J Cardiometab Syndr, 2*(3), 183-189.

Ferrara, C. M., McCrone, S. H., Brendle, D., Ryan, A. S., & Goldberg, A. P. (2004). Metabolic effects of the addition of resistive to aerobic exercise in older men. *Int J Sport Nutr, 14*, 73-80.

Gaesser, G. A., Angadi, S. S., & Sawyer, B. J. (2011). Exercise and diet, independent of weight loss, improve cardiometabolic risk profile in overweight and obese individuals. *Phys Sportsmed, 39*(2), 87-97.

Giada, F., Vigna, G. B., Vitale, E., Baldo-Enzi, G., Bertaglia, M., Crecca, R., & Fellin, R. (1995). Effect of age on the response of blood lipids, body composition, and aerobic power to physical conditioning and deconditioning. *Metabolism, 44*(2), 161-165.

Hagerman, F., Walsh, S., Staron, R., Hikida, R., Gilders, R., Murrary, T., & Ragg, K. (2000). Effects of high-intensity resistance training on untrained older men. I. Strength, cardiovascular, and metabolic responses. *Gerontol A Biol Sci Med Sci 55*(7), B336-B346.

Hernelahti, M., Kujala, U., Kaprio, J., & Sarna, S. (2002). Long-term vigorous training in young adulthood and later physical activity as predictors of hypertension in middle-aged and older men. *Int J Sports Med, 23*(3), 178-182.

Hinton, P. S., Nigh, P., & Thyfault, J. (2015). Effectiveness of resistance training or jumping-exercise to increase bone mineral density in men with low bone mass: A 12-month randomized, clinical trial. *Bone, 79*, 203-212.

Hu, G., Bouchard, C., Bray, G. A., Greenway, F. L., Johnson, W. D., Newton, R. L., Katzmarzyk, P. T. (2011). Trunk versus extremity adiposity and cardiometabolic risk factors in white and African American adults. *Diabetes Care, 34*(6), 1415-1418.

Joseph, L. J., Davey, S. L., Evans, W. J., & Campbell, W. W. (1999). Differential effect of resistance training on the body composition and liporotein-lipid profile in older men and women. *Metabolism, 48*(11), 1474-1480.

Kettunen, J. A., Kujala, U. M., Kaprio, J., & Sarna, S. (2006). Health of master track and field athletes: a 16-year follow-up study. *Clin J Sport Med 16*(2), 142-148.

Kusy, K., & Zielinski, J. (2015). Sprinters versus long-distance runners: how to grow old healthy. *Exerc Sport Sci Rev, 43*(1), 57-64.

Kusy, K., Zieliński, J., & Pilaczyńska-Szcześniak, Ł. (2013). Insulin sensitivity and β-cell function estimated by HOMA2 model in sprint-trained athletes aged 20− 90 years vs endurance runners and untrained participants. *J Sport Sci, 31*(15), 1656-1664.

Law, M. R., Wald, N. J., & Thompson, S. (1994). By how much and how quickly does reduction in serum cholesterol concentration lower risk of ischaemic heart disease? *BMJ, 308*(6925), 367-372.

Leenders, M., Verdijk, L. B., van der Hoeven, L., van Kranenburg, J., Nilwik, R., & van Loon, L. J. (2013). Elderly men and women benefit equally from prolonged resistance-type exercise training. *J Gerontol A Biol Sci Med Sci, 68*(7), 769-779.

Martins, R. A., Veríssimo, M. T., e Silva, M. J. C., Cumming, S. P., & Teixeira, A. M. (2010). Effects of aerobic and strength-based training on metabolic health indicators in older adults. *Lipids Health Dis 9*(1), 1.

Mikkelsen, U., Couppe, C., Karlsen, A., Grosset, J., Schjerling, P., Mackey, A., . . . Kjær, M. (2013). Life-long endurance exercise in humans: circulating levels of inflammatory markers and leg muscle size. *Mech Ageing Dev, 134*(11), 531-540.

Moreira, M. M., Souza, H. P. C. d., Schwingel, P. A., Sá, C. K. C. d., & Zoppi, C. C. (2008). Effects of aerobic and anaerobic exercise on cardiac risk variables in overweight adults. *Arq Bras Cardiol, 91*(4), 219-226.

Nederveen, J., Joanisse, S., Séguin, C., Bell, K., Baker, S., Phillips, S., & Parise, G. (2015). The effect of exercise mode on the acute response of satellite cells in old men. *Acta Physiol 215*(4), 177-190.

Neves, M. F., Virdis, A., Sanjuliani, A. F., & Tibiriçá, E. V. (2013). Hypertension and cardiometabolic risk factors. *Int J Hypertens, 2013*.

Nichols, J. F., Palmer, J. E., & Levy, S. S. (2003). Low bone mineral density in highly trained male master cyclists. *Osteoporos Int, 14*(8), 644-649.

Norton, K. (2005). *Sports Medicine Australia pre-exercise screening system*. Retrieved from Sports Medicine Australia (SMA):

World Health World Health Organization (2006). Definition and diagnosis of diabetes mellitus and intermediate hyperglycaemia: report of a WH.

Perloff, D., Grim, C., Flack, J., Frohlich, E. D., Hill, M., McDonald, M., & Morgenstern, B. Z. (1993). Human blood pressure determination by sphygmomanometry. *Circulation, 88*(5), 2460-2470.

Pirillo, A., Norata, G. D., & Catapano, A. L. (2014). Postprandial lipemia as a cardiometabolic risk factor. *Curr Med Res Opin, 30*(8), 1489-1503.

Reaburn, P., & Dascombe, B. (2009). Anaerobic performance in masters athletes. *Eur Rev Aging Phys 6*(1), 39-53.

Reaburn, P., Logan, P., & Mackinnon, L. (1994). *The Effect of Hypertrophy Resistance Training on Anaerobic Work Capacity in Veteran Sprint Runners.* Retrieved from Canberra, Australia: Australian Sports Commission:

Rector, R. S., Rogers, R., Ruebel, M., & Hinton, P. S. (2008). Participation in road cycle-racing vs running is associated with lower bone mineral density in men. *Metabolism, 57*(2), 226-232.

Schell, J., & Leelarthaepin, B. (1990). *Physical fitness assessment in exercise and sport science*: Leelar Biomediscience Services.

Sharman, J. E., & Stowasser, M. (2009). Australian Association for Exercise and Sports science position statement on exercise and hypertension. *J Sci Med Sport, 12*(2), 252-257.

Sillanpää, E., Laaksonen, D. E., Häkkinen, A., Karavirta, L., Jensen, B., Kraemer, W. J.,Häkkinen, K. (2009). Body composition, fitness, and metabolic health during strength and endurance training and their combination in middle-aged and older women. *Eur J Appl Physiol, 106*(2), 285-296.

Sutherland, W., Woodhouse, S., Williamson, S., & Smith, B. (1981). Decreased and continued physical activity and plasma lipoprotein lipids in previously trained men. *Atherosclerosis, 39*(3), 307-311.

Tanner, R., & Gore, C. (2013). *Physiological tests for elite athletes*: Human Kinetics.

Thompson, P. D., Cullinane, E., Sady, S., Flynn, M., Bernier, D., Kantor, M., . . . Herbert, P. (1988). Modest changes in high-density lipoprotein concentration and metabolism with prolonged exercise training. *Circulation, 78*(1), 25-34.

Treuth, M., Ryan, A., Pratley, R., Rubin, M., Miller, J., Nicklas, B., Hurley, B. (1994). Effects of strength training on total and regional body composition in older men. *J Appl Physiol, 77*(2), 614-620.

Wallman, K., Plant, L. A., Rakimov, B., & Maiorana, A. J. (2009). The effects of two modes of exercise on aerobic fitness and fat mass in an overweight population. *Res Sports Med, 17*(3), 156-170.

Westcott, W. L., Winett, R. A., Annesi, J. J., Wojcik, J. R., Anderson, E. S., & Madden, P. J. (2009). Prescribing physical activity: applying the ACSM protocols for exercise type, intensity, and duration across 3 training frequencies. *Phys Sportsmed, 37*(2), 51-58.

Zachwieja, J. J., Toffolo, G., Cobelli, C., Bier, D. M., & Yarasheski, K. E. (1996). Resistance exercise and growth hormone administration in older men: effects on insulin sensitivity and secretion during a stable-label intravenous glucose tolerance test. *Metabolism, 45*(2), 254-260.

6

Manuscript 5 –

Performance Benefits of Concurrent resistance and sprint cycling training

This chapter is presented with the text formatting and referencing styles required by the *Journal of Strength and Conditioning Research.*

Declaration of Co-Authorship and Contribution

Title of Paper	Effects of concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters road cyclists.
Full bibliographic reference for Journal/Book in which the Paper appears	**Del Vecchio**, L., Stanton R., Reaburn, P., Macgregor, C., Meerkin, J., Korhonen, M.T. (2016). Effects of concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters road cyclists. *Journal of Strength and Conditioning Research*.
Status	Submitted and in review

Nature of Candidate's Contribution

Luke Del Vecchio conceived the research idea, designed the experiment, collected data, , statistically analysed the data, drafted manuscript in full, edited the manuscript based on co-author feedback, submitted the manuscript, and responded to reviewer comments.

Nature of Co-Authors' Contributions

Peter Reaburn and Marko Korhonen refined the experimental design, reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Robert Stanton, Campbell Macgregor and Jarrod Meerkin reviewed manuscript drafts and provided feedback for inclusion, reviewed the final manuscripts and reviewed responses to reviewer comments.

Please Note the reference format in the following paper is "as per the journals required referencing format".

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Publication of Research Higher Degree Work for Inclusion in the Thesis Procedures.

Signature:

Date: 20th June 2016

Effects of concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters road cyclists.

6.1 Abstract

Concurrent strength and sprint training has been shown to increase muscle mass and various performance characteristics in younger athletes. However, the effectiveness of concurrent training in masters road cyclists remains unclear. Therefore, the aim of this study was to examine the effect of a 12 week concurrent strength and sprint training program on lean mass, strength, power and sprint performance in masters road cyclists. Twenty five masters cyclists were assigned to a concurrent strength and sprint training group (CT; n=9, 53.5 ± 9.3 years), a sprint training group (ST, n=7, 49.4 ± 4.8 years) or a control group (CG, n=9, 56.9 ± 8.6 years). Before and after the 12 week intervention, whole body lean mass (WBLM), total lower limb lean mass (LLLM), countermovement jump height (CMJ) and peak isometric torque of quadriceps (QPT) and hamstring (HPT) muscles were examined. For evaluation of sport-specific performance, 10 second sprint cycling peak power (PP10), total 30 second work (TW), maximal aerobic power (MAP) and flying 200 meter time trial performance (TT) were assessed. No pre-training differences were observed between CT, ST and CG groups for any of the dependent variables. After training, a significant ($p<0.05$) between group difference was observed in TW between CT and CG groups. A significant effect of time ($p<0.05$) was observed for LLLM in CT and ST groups, and for TT in the CT group. These results suggest including strength and sprint exercises in training can increase LLLM and TT in endurance trained masters road cyclists.

6.2 Introduction

Masters athletes are typically older than 35 years of age and systematically train for, and compete in, organized forms of sport (30). Over recent years there has been a significant increase in the number of masters athletes continuing to train and compete at high performance levels within both individual sports and multi-sport events designed for masters athletes (37). Competitive road cycling is becoming increasingly popular among masters athletes. For example, the number of competitive masters road cyclists in Australia has grown from about 4,000 in 2013 to 10,000 in 2015 (3).

In younger cyclists, strength training has been shown to increase cycling efficiency and power output at VO_{2max} (32). In masters road cyclists, strength training improves cycling efficiency (21) and finally, in older non-athletes, strength training has been shown to improve cycling peak power output (11). However, despite the well-known benefits of strength training for younger cyclists (39) and healthy older adults (7), masters endurance cyclists appear not to engage in regular strength training (23).

Previous research has shown that an age-related decline in lean mass contributes to the age-related declines in aerobic and anaerobic performance in both untrained older adults (12) and masters athletes (30). Importantly, strength training has been shown to increase lean mass in previously untrained older people (36). Moreover, strength training has been shown to increase lean mass and leg strength of masters endurance runners (29) and masters sprint runners (9). However, the effectiveness of strength training to increase lean mass in endurance-trained masters cyclists is currently unknown.

Recently, there has been growing interest in sprint training as an alternative modality for increasing physical performance and muscle mass in older adults (27). For example, in healthy older men sprint training has been shown to increase lean muscle mass (27). Moreover, when combined with strength training, sprint training may have an additive effect on both lean muscle mass and strength (6, 9). However, the effect of sprint training or concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters cyclists remains unstudied.

It is well known that endurance training provides many health benefits, particularly among masters athletes who participate in endurance orientated sports (26). However, some research suggests endurance training may not provide a sufficient stimulus to prevent age-related losses in muscle mass and strength (10, 25). In masters endurance athletes, it might be suggested that replacing a portion of endurance training with strength training and sprint training may be necessary to limit the age-related decline in lean mass, strength, power and sprint performance. In endurance cyclists sprint and / or strength training is important for a number of reasons. First, leg power is needed to accelerate rapidly during a breakaway attack in road racing. Second, leg strength and power are needed during hill climbing. Finally, sprinting peak power and speed are needed during the typical sprint to the finish observed in road cycling races. Therefore, the purpose of this study was to examine the effect of a 12 week concurrent strength and sprint training program on lean mass, strength, power and sprint performance in masters road cyclists. We hypothesised that 12 weeks of concurrent strength and sprint cycling training, would significantly increase lean mass, strength, power and sprint performance in masters road cyclists.

6.3 Methods

6.3.1 Experimental Approach to the problem

It was hypothesised that concurrent strength and sprint cycling training added to regular endurance cycling training would lead to a significant increase in lean body mass, muscular strength and power, and sprint performance in master road cyclists. A parallel, three-group, randomized intervention (pre-post-test) experimental design was used. To investigate the possible effects of CT on strength, power and sprint performance in master endurance cyclists, Dual Energy X-Ray Absorptiometry (DEXA) measures of whole body lean mass (WBLM) and total lower limb lean mass (LLLM) plus countermovement jump height (CMJ), peak isometric torque of quadriceps (QPT) and hamstring (HPT) muscles were examined. For evaluation of sport-specific performance, 10 second sprint cycling peak power (PP10), total 30 second work (TW), maximal aerobic power (MAP) and flying 200 meter time trial performance (TT) were measured before and after a 12 week intervention period. All subjects performed familiarization trials before the testing days. Twenty-five masters endurance engaged in the same endurance training program were randomly assigned to one of the following three groups: concurrent strength and sprint cycling training group (CT), sprint cycling training group (ST) and a control group (CG). The CT group replaced four (50%) of their usual endurance cycling sessions with two strength training sessions and two sprint training sessions, the ST group replaced two of their usual endurance cycling sessions with two sprint training sessions; and the CG group maintained their normal endurance training. We used as the independent variable, the group, whereas the dependent variables were WBLM, LLLM, CMJ, QPT, HPT, PP10, TW, MAP and TT.

6.3.2 Participants

The study was approved by the Central Queensland University Human Research Ethics Committee. Twenty-five healthy male masters cyclists aged between 41 and 76 years with no background of strength training were recruited and provided written informed consent. The subjects were required to be involved in regular cycling training and/or road cycling competition for a minimum of two years and to be achieving a minimum of eight hours of endurance cycling training per week. All subjects underwent pre-exercise screening to ensure they had no established cardiovascular, metabolic or respiratory disease nor signs or symptoms of disease (28).

Random allocation of participants into training groups was not possible as the majority of participants had both work and family commitments that limited their availability to participate in the ST or CT training programs. As a result, subjects were allocated to either a control group (CG, n=10), sprint cycling group (ST, n=7) or concurrent strength and sprint cycling training group (CT, n=10). For personal reasons, one participant from the CT group and one subject from the CG group withdrew from the study, subsequently reducing the CT group to nine participants (CT, n=9) and the control group to nine participants (CG, n=9). Subjects were instructed not to change their diet or lifestyle over the experimental period. The physical characteristics of each group are shown in Table 6.1.

Table 6.1. Physical and training characteristics of participants

	Resistance & Track Sprint-cycling Group (n=9)	**Track Sprint-cycling Only Group (n=7)**	**Control Group (n=9)**
Age (years)	53.5 ± 9.3	49.4 ± 4.8	56.9 ± 8.6
Stature (m)	1.80 ± 0.1	1.80 ± 0.1	1.75 ± 0.1
Body mass (kg)	81.9 ± 6.1	78.5 ± 6.1	83.5 ± 10.0
Training hours (hr/week)	8.2 ± 1.0	8.1 ± 1.3	8.0 ± 1.2

Data are Mean ± SD

6.3.3 Procedures

Subjects attended the laboratory (22ºC, 60% RH) following an overnight fast and did not consume caffeine the morning of the test. All tests were carried out between 0700 and 0900 hours. Pre- and post-intervention testing included measures of anthropometry, DEXA, jumping performance on a force-plate, peak isometric torque of quadriceps and hamstring muscle groups, ten second sprint cycling peak power, total 30 second work and maximal aerobic power on a cycle ergometer. The flying 200 meter time trial performance test was performed at a local, outdoor cycling velodrome. Figure 6.1 over the page shows the order of tests.

6.3.4 Body composition

Stature (m) and body mass (kg) were measured with a stadiometer and medical scales (Seca, Birmingham, UK) with participant’s unshod and wearing cycling apparel. DEXA (Hologic Discovery-W, Bedford, MA.) was used to measure WBLM and LLLM. A Certified Clinical Densitometrist (CM) performed all DEXA data collection and analysis procedures. Prior to each measurement session an automatic calibration procedure was performed to assess and maintain the measurement precision and accuracy of the DEXA. During the procedure, subjects lay motionless in a supine position on a table for 8 minutes, while an X-ray fan array passed above the table. WBLM and TLLM were determined using manufacturer-supplied software (APEX version 4.0, Hologic Discovery).

6.3.5 Laboratory measures

Following the DEXA scan, and prior to all laboratory testing, a 15-minute warm up consisting of 5 minutes of cycling at 50 watts on a cycle ergometer (Velotron Dynafit Pro, RaceMate, Seattle, WA, USA), followed by 10 body weight squats, 10 heel raises and 10 countermovement jumps (CMJ) was performed. All were undertaken at moderate intensity. Participants then completed the following tests; CMJ, QPT, HPT, PP10, TW and MAP.

6.3.6 Muscular power

Muscular power was assessed using a CMJ test. These trials were performed three times on an AMTI force plate (Advanced Medical Technology Inc., Watertown, USA). The analogue signal sampled at 1000Hz was converted to a digital signal using a Powerlab 30 series data acquisition system (AD Instruments, Sydney, Australia), and data were collected using custom-written LabView software Version 2011 (National Instruments, Texas, USA). The vertical force-time data were filtered using a fourth-order Butterworth low-pass filter with a cut-off frequency of 17 Hz. Participants were instructed to perform a fast downward movement (to 90º knee flexion) immediately followed by a fast upward movement, and to jump as high as possible. Hands were kept on the hips to minimize any influence of the arm swing. Each trial was followed by 2 minutes of passive rest, and the mean of three jumps (cm) was used for further analysis.

6.3.7 Muscular strength

Quadriceps and hamstring peak isometric torque (QPT and HPT) of the dominant leg was measured seated; with the knee agnle fixed at 90 degrees, using a Biodex isokinetic dynamometer system 3 (Biodex Medical Systems, Shirley, NY, USA). Subjects performed three x 10-second maximal isometric knee extensions (QPT) and three 10-second maximal isometric knee flexions with strong verbal encouragement. The effort with the highest peak torque ($Nm \cdot kg^{-1}$) was used for subsequent data analysis.

6.3.8 Anaerobic performance

Sprint cycling performance was measured using 10 and 30 second sprint tests on a Velotron ergocycle (Racermate, Seattle, USA) with a 5-minute passive rest period between tests. Following familiarisation of the protocol and a warm-up consisting of pedalling at a self-selected cadence at a set resistance of 50 W for five minutes interspersed with three practice maximal accelerations over 2-3 seconds, the resistance of the ergocycle was adjusted at 75

$g \cdot kg^{-1}$ of body mass (40). Peak power ($W \cdot kg^{-1}$) in the 10-second test and total 30 second work ($kJ \cdot kg^{-1}$) was used for subsequent data analysis.

6.3.9 Maximal aerobic power

A graded maximal exercise test to measure MAP was completed on an electrically-braked, computer controlled cycle ergometer (Velotron Dynafit Pro, RaceMate, Seattle, USA). Gas analysis was undertaken using a Fitmate Pro (Cosmed, Rome, Italy) following a 5-minute warm-up at 30 W cycling and a pedalling cadence of 90 rpm throughout the test. The work increments for each 1-minute stage were 15 W. The test ceased when two or more criteria for attainment of VO_{2peak} were achieved. These criteria included no significant increase in O_2 uptake with an increase in work rate, attainment of the age-predicted maximum heart rate, and/or volitional exhaustion (33). MAP was calculated from the last completed work rate, plus the fraction of time spent in the final non-completed work rate multiplied by 25 watts (16).

6.3.10 Flying 200 meter time sprint time

Forty-eight hours after the laboratory tests, flying 200 meter sprint time was assessed at a local concrete and banked (31 degrees), 333.3 m cycling velodrome with participants using their own road bikes to perform a total of three flying 200 meter attempts. Following a ten lap warm up, participants then performed two familiarisation attempts of the flying 200 meter time trial before ten minutes of passive seated rest. The flying 200 meter time trial commenced by each participant cycling around the velodrome two times in attempt to build up speed, and on the third lap, participants were instructed to come down the bank of the velodrome at maximal speed when crossing the starting line. Flying 200 meter sprint time was recorded by three, experienced observers using hand-held stopwatches (Hart sports timer 898, Hart Sport, Aspley, Australia). Observers were instructed to start the stopwatches when the participant crossed the start line with the front end of the front wheel and stop the stopwatches when the participant crossed the finish line with the front wheel. The mean of three trials was recorded for subsequent analysis.

6.3.11 Sprint cycling training program

The sprint cycling training program was designed in consultation with an accredited track cycling coach and supervised by the same coach for each of the twice weekly sessions. Both CT and ST groups performed two sprint cycling training sessions per week, separated by 48 hours. Sprint cycling sessions consisted of a five to ten minute warm-up (10-15 x 330m laps at a self-selected pace) after which subjects performed 1-3 sets x 1-3 repetitions of maximal effort sprints ranging in distance from 65 meters to 330 meters with 2-3 min of active then passive recovery between repetitions and 10 minutes passive rest between sets. At the completion of the track training session, subjects performed a 5 to 10 minute cool down (10-15 laps of the velodrome at a self-selected pace). Using an undulating periodization program; participants commenced the track program using a 92 inch gear and throughout the 12-week period, progressed to a 104 inch gear. The overall training adherence rate calculated as a percentage of the total sprint cycling training sessions successfully completed was 87 ± 4.1% for the CT group and 82 ± 5.1% for ST group across the 12-week study period.

6.3.12 Resistance training program

The CT group replaced four of their usual weekly endurance cycling training sessions with two evening group track sprint-cycling training sessions as described above, and two morning group gym-based strength training sessions per week. Participants were advised to perform two 45-60 minute recovery rides (50-70% MHR, 90-110rpm) and not undertake other cycling training sessions throughout the training week to avoid overtraining and excessive fatigue. All four training sessions were supervised by an accredited strength and conditioning coach. Strength training sessions were conducted on alternate days to the track sprint training days. The strength training program and relative volumes of the different modes of strength during the course of the study are summarized in Table 6.2. During each training session, subjects performed the following exercises in order: double leg vertical and horizontal hops or jumps, single leg alternating box jumps, leg press throws, single-leg leg presses, seated hip flexions, leg curls, leg extensions, seated calf-raises, supine hip extensions, chest press, bench rows, abdominal curl ups and lower back extensions. Recovery time of two minutes between sets and exercises was strictly controlled, and each strength training session lasted approximately 90 minutes. The strength training program incorporated an undulating periodization approach, to reduce the potential for overtraining and to optimise adaptation. Subjects completed electronic training logs (Accelaware, Sports Performance Systems, Brisbane, Australia) describing all their training parameters (number of repetitions, sets, loads, distances, track sprint cycling times) to monitor progress and to provide motivation for maximal effort during the training program. The overall strength training adherence rate, calculated as a percentage of training sessions successfully completed, was 85 ± 3.8% for CT group across the 12-week study period.

Table 6.2. Mixed methods resistance training program

12 week strength training program					
	PHASE 1			PHASE 2	
Weeks	**1-4**	**4-6**	**6-8**	**8-10**	**10-12**
Reps	Hyp: 8-12	S: 6	S: 4	H: 8-12	S: 6
		EE: 6	EE: 4	S: 6	EE: 4-6
		Ply: 10	Ply: 8	Ply: 6	Ply: 8
Sets	Hyp: 4	S: 3	S: 3	H: 3	S: 4
		EE: 3	EE: 4	S: 3	EE: 4
		Ply: 2	Ply: 2	Ply:3	Ply: 2
Load (%1RM)	Hyp: 50-60%	S: 75%	S: 80%	H: 70%	S: 95%
		EE: 35%	EE: 40%	S: 85%	EE: 50%
		Ply: 80 FC	Ply: 90 FC	Ply: 100 FC	Ply: 110FC
Rest Periods	1 minute			Hyp: 1 min	
		EE/S/Ply: 2-3min	EE/S/Ply: 2-3min	EE/S/Ply: 2-3min	EE/S/Ply: 2-3min

Hyp = hypertrophy; S = strength; EE = explosive exercises; Ply = plyometrics; FC = foot contacts

6.3.13 Data Analysis

The training related effects were measured using a three-way ANOVA were used to determine group (CT, ST, CG) x time (Pre, Post) interactions, or main effects where no interaction effect existed. If an interaction effect was noted, a Tukey post-hoc test was undertaken to identify the source of the differences. A p value of <0.05 was considered statistically significant. Twenty-three of the twenty-four dependent variables were normally distributed, as assessed by Shapiro-Wilk's test ($p>0.05$), although one variable did not meet the assumption of normality (Post_PP10; $p = 0.033$). Attempts to log transform the data did not change the overall outcome for this variable and therefore parametric statistics were used. Cohen's conventions for effect size (ES) were used for interpretation for no effect (ES<0.2), small effect (0.2-0.49), moderate effect (0.5-0.79), and large effect

(<0.8) (4). The SPSS Version 20 (IBM, Corp, New York) software was used for all statistical analyses.

6.4 Results

Pre and post-test values for each dependent variable for each of the intervention groups are shown in Table 6.3. No pre-training differences were observed between the CT group, ST group and CG group for any of the dependent variables.

6.4.1 Lean mass

No changes in WBLM occurred during the intervention in all groups ($F(2, 22) = 0.11$, $p = 0.18$) (Table 6.3). There were no significant between group effects for TLLM ($F(2,22) = 2.7$, $p = 0.89$). However there was a significant effect of time ($F(1, 22) = 10.61$, $p = 0.04$), with TLLM increasing in the CT group ($p = 0.01$, 4.5%, ES = 0.35), and in the ST group ($p = 0.03$, 3.5%, ES = 0.45) with training.

6.4.2 Muscular power

No changes in CMJ occurred during the intervention in all groups ($F(1, 24) = 0.48$, $p = 0.49$). (Table 6.3).

6.4.3 Muscular strength

No changes in either QPT or HPT occurred during the intervention in all groups. ($F(2, 22) = 2.61$, $p = 0.96$); ($F(2, 22) = 2.32$, $p = 0.14$) (Table 6.3).

6.4.4 Sprint cycling performance

A significant group x time interaction was observed for PP10 ($F(2, 22) = 3.50$, $p = 0.48$), however subsequent post hoc analysis revealed no differences between groups (Table 6.3).

A significant group x time interaction was also observed for TW ($F(2, 22) = 5.59$, $p = 0.01$, 6.9%, ES = -0.59), subsequent a Tukey post hoc analysis revealed a difference in TW between ST and CG groups (ST>CG) ($p = 0.02$).

6.4.5 Maximal aerobic power

No changes in MAP occurred during the intervention in all groups ($F(2, 22) = 1.61$, $p = 0.22$) (Table 6.3).

6.4.6 Flying 200 meter sprint time

A significant group x time interaction was observed for sprint TT performance (F, (2, 22) = 11.70, $p = 0.03$), however subsequent post hoc analysis revealed no differences between groups. (Table 6.3). There was also a significant effect of time ($F(1, 22) = 7.21$, $p = 0.01$), with faster TT performance in the CT group ($p < 0.01$, -7.7%, ES = 0.85). In the control group, TT performance slowed ($p = 0.07$, -8.8%, ES = 0.85).

Table 6.3. Changes in lean mass, laboratory measures and 200m sprint cycle performance following 12 weeks of CT or ST

	Track & Strength Group		Effect Size	Track Only Group		Effect Size	Control Group		Effect Size
	Pre	Post		Pre	Post		Pre	Post	
WBLM (kg)	61.8 ± 5.2	63.1 ± 5.4	0.26 small	61.4 ± 4.7	61.6 ± 5.1	0.16 No effect	61.5. ± 5.5	60.6 ± 6.2	-0.15 No effect
LLLM (kg)	17.6 ± 1.9	18.4 ± 2.3†	0.35 small	17.0 ± 1.5	17.6 ± 1.4†	0.45 small	16.0 ± 2.0	16.0 ± 1.9	0.00 No effect
CMJ (cm)	24.4 ± 3.8	24.9 ± 4.4	0.12 no effect	25.1 ± 12.0	22.7 ± 24.3	-0.12 no effect	23.9 ± 7.0	21.7. ± 6.3	-0.33 Small effect
QPT (Nm·kg^{-1})	2.8 ± 0.5	3.0 ± 0.4	0.47 small	3.1 ± 0.4	2.9 ± 0.4	-0.50 small	2.6 ± 0.6	2.4 ± 0.8	-0.28 Small effect
HPT (Nm·kg^{-1})	1.0 ± 0.2	1.1 ± 0.2	0.32 small	1.0 ± 0.2	1.1 ± 0.1	0.53 Moderate	1.0 ± 0.1	0.9 ± 0.3	-0.44 Small effect
PP10 (W·kg)	11.3 ± 1.8	11.5 ± 1.9	0.10 no effect	11.6 ± 1.2	12.0 ± 1.1	0.38 small effect	10.5 ± 1.2	9.8 ± 1.9	-0.44 Small effect
TW (J·kg)	247.4 ± 35.0	255.1 ± 35.8	0.22 small effect	256.0 ± 28.5	262.4 ± 19.2*	0.26 Small effect	227.5 ± 20.8	211.8 ± 30.9†	-0.59 Moderate effect
MAP (watts)	341.6 ± 62.6	338.8 ± 60.0	0.04 No effect	362.5 ± 37.7	378.1 ± 48.9	0.35 Small effect	316.6 ± 54.4	308.3 ± 59.9	-0.14 No effect
TT (s)	16.0 ± 1.9	14.7 ± 1.3†	0.85 large	14.7 ± 1.1	14.2 ± 0.6	0.61 Moderate	15.4 ± 1.0	15.9 ± 1.2	-0.45 Small effect

Effect size = between group effect size. * Between-group difference estimated by ANOVA: Tukey post-hoc test ($P < 0.05$); † = Significant effect of time ($p < 0.05$); WBLM = whole body Lean mass; LLLM = total lower limb lean mass; CMJ = counter movement jump height; QPT = quadriceps peak isometric torque; HPT = hamstring peak isometric torque; PP10 = ten second sprint peak power; TW = total 30 second work; TT = flying 200 meter sprint time; MAP = maximal aerobic power in incremental cycle ergometer test.

6.5 Discussion

The purpose of this study was to examine the effect of a 12 week concurrent strength and sprint training program on lean mass, strength, power and sprint performance in a group of masters road cyclists who had no previous experience in strength and sprint training. The major finding was that 12 weeks of concurrent strength and sprint training significantly increased LLLM and significantly improved TT performance in well trained masters road cyclists.

Our finding of training induced changes in LLLM are in agreement with previous research, which has reported significant increases in muscle mass or fiber area in response to a combined strength and sprint training intervention in masters sprint runners (9, 31). For example, Cristea et al. (9) reported a significant 20% increase in the cross-sectional area of type II muscle fibers (Vastus Lateralis) in a group of male masters sprint runners (n=7, 71.0 ± 5.0 years) who completed a 20 week progressive strength and sprint training program. In an earlier report, Reaburn et al. (31) demonstrated a significant 3.4% increase in mid-thigh circumference in a group of male masters sprint runners (n=8, 54.7 ± 5.5 years), who completed eight weeks of hypertrophy training. Piacentini et al. (29) reported a non-significant 2% increase in lean mass in a group (n=6, 44.2 ± 3.9 years) of male and female masters endurance runners following six weeks of concurrent endurance running and strength training. However the duration of the latter study (six weeks), may not have been long enough to observe significant changes in lean mass, as it is generally understood that muscle hypertrophy requires greater than eight weeks of strength training (35). The present study found 12 weeks of CT training significantly increased LLLM (4.5%) which is slightly higher than the findings of Piacentini et al. (20) and Reaburn et al. (31), but signifcantly lower than the findings of Cristea et al (12). Importantly, the present study combined strength and sprint training. Previous studies suggest sprint training may be a more complementary training modality to strength training for muscle hypertrophy than endurance training (6).

Little is known about the mechanisms that are responsible for inducing muscle hypertrophy from sprint training in healthy older adults or masters athletes, however recent research examining the effect of sprint training in healthy older adults suggests this type of training may exert a positive effect on myofibrillar protein fractional synthetic rate and satellite cell expansion (27). For instance, Bell et al. (27) recently reported myofibrillar protein fractional synthetic rate was significantly elevated at 24 and 48 hours in a group of healthy, older males (n=22, 60-75 years) following a bout of 10 x 1 minute cycling-sprints performed on a cycling ergometer. Moreover, Naderveen et al. (27) observed significant satellite cell pool expansion was greater following an acute bout of cycling sprints than after an acute bout of moderate intensity aerobic exercise in a group of healthy, older males (n=22, 67.0 ± 7 years). Expansion of satellite cell pools is associated with an increase in lean mass in younger adults (5). Taken together, these data suggest ST training may induce acute mechanisms favourable for muscle hypertrophy in healthy older adults.

The ST group in the current study demonstrated a 3.5% increase in LLLM which is surprisingly higher than the increases in lean mass reported in younger cohorts who have undergone sprint interval training programs lasting between eight weeks to eight months (17, 24). These differences may be explained by the use of heavy gearing in the present study with the ST gearing progressively increased over the 12 week training program, thus providing a form of progressive overload that may have stimulated an increase LLLM. Taken together, the results of the current study suggest ST training positively affects lean mass in masters cyclists. These findings support the use of ST training as an alternative exercise intervention to increase lower limb lean mass in masters road cyclists.

In the present study, CMJ did not significantly increase following 12 weeks of CT training. These results are in contrast to the findings of Cristea et al. (9) who reported a significant improvement in squat jump height in a group of male masters sprint runners (n=7, 71.0 ± 5.0 years) who completed a 20 week progressive strength training program. However, the previous researchers used a squat jump test which does not utilize the stretch-shortening cycle, making a true comparison of the present results difficult. In contrast, the lack of a significant increase in CMJ following 12 weeks of concurrent resistance and sprint training observed in the current study are in agreement with the findings of Piacentini et al. (29) who reported six weeks of concurrent endurance running and strength training did not significantly improve CMJ in a group (n=6, 44.2 ± 3.9 years) of male and female masters endurance runners. Despite not reaching significance, the participants in the study of Piacentini et al. (29) study improved CMJ height by 3.2% which is similar to the 2.7% increase in CMJ observed in the CT group. A lack of a significant improvement in CMJ in the current study, may also be attributed to a possible interference effect known to affect explosive strength when strength training is combined with endurance training (14). Despite reducing their endurance training volume, the CT group still performed several endurance sessions a week throughout the whole study period. Taken together, these results suggest 12 weeks of CT training or ST training may not significantly improve muscular power in masters road cyclists.

In the present study 12 weeks of CT training did not significantly improve QPT or HPT in the CT group. Age-related declines in muscular strength is commonly associated with the age-related loss of lean mass observed in masters runners, swimmers and cyclists (1). These age-related declines in muscular strength and muscle mass may contribute to the observed reduction in cycling performance with age. Interestingly, although not significant, HPT increased by 5.7% and QPT by 7.1% in the present study. These results are clearly lower than reported changes in strength following concurrent strength and sprint running training in masters sprint runners (9). For example, Cristea et al. (9) reported 20 weeks of concurrent strength and sprint training increased quadriceps MVC by 21% and hamstrings MVC by 40% in male masters sprint runners. It has been shown that strength improvements are lower when endurance training is combined with a strength training program (14) as a result of conflicting cellular stimuli (18). In the current study, participants in the CT group performed up to three endurance training sessions per week throughout the 12 week CT program, which could explain the smaller increases in QPT (7.1%) and HPT (5.7%) observed in the current study. Taken as a whole, these data suggest 12 weeks of CT training does not significantly increase knee extension or knee flexion isometric strength in masters road cyclists.

In the present study, 12 weeks of ST did not significantly improve QPT (-6.6%) or HPT (9.5%). To the best of our knowledge, no studies to date, have investigated the effects of ST on muscle strength in masters cyclists. However, in younger cohorts, repeat sprint training has been shown to increase isometric knee extension strength (6, 15). For example, Harridge et al. (15) reported a significant increase in maximal isometric knee extensor torque (7%) following six weeks of sprint cycling training, performed four times per week, in a group of recreationally active, younger males (n=7, 22 ± 2 years). In the current study, we observed a significant decline in HPT, this decrease may be explained by the change in cycling training the ST group were exposed to throughout the 12 week ST program. For instance, previous studies have indicated hamstring muscle recruitment increases when cycling cadence increases, and when posture changes from sitting to standing (34). The ST program incorporated several standing sprint starts, with an emphasis on maximal cadence, which may have contributed to the increased hamstring muscle recruitment, and subsequently decreased quadriceps muscle recruitment observed in the ST group. Interestingly, the control group in the present study also demonstrated a 5.4% decline in QPT and a 5.0% decline in HPT over the 12 week period. These results suggest endurance cycling training in combination with or without additional ST training may not provide a strong enough stimulus to prevent the loss of knee extensor strength with age. In summary, the present results suggest 12 weeks of ST training does not significantly increase knee flexion or knee extension strength in masters road cyclists.

The ability to generate brief, high powered outputs is an important component of competitive cycling performance (2). In the present study, 12 weeks of CT training did not significantly increase PP10 in the CT group. No research to date, has investigated the effects of CT training on PP10 or TW in healthy older adults or masters cyclists. However, in a cross sectional analysis of highly trained masters cyclists (n= 173, 35-64 years) Gent and Norton (13) reported PP10 and TW declined by 8.1% and 8.0% per decade. In the current study, 12 weeks of CT resulted in a non-significant increase in PP10 by 1.7% and TW by 3.1%; these results suggest CT training, if maintained, may help reduce the age-related decline in sprint cycling performance observed in masters cyclists. However, more longitudinal studies are needed to confirm this hypothesis.

In the current study, 12 weeks of ST did not significantly improve PP10 or TW in the ST group. These results are in contrast to similar studies in younger cohorts (8), which have reported significant improvements in TW. For example Creer et al. (8) reported 4 weeks of sprint cycling training, performed twice per week, significantly increased total 30 second work (6.0%) as measured by cycle ergometry, in a group of younger, trained cyclists (n=10, 25.1 ± 2.3 years). In the present study, the CT group improved PP10 by 1.7% and TW by 3.1 %, whereas the ST group improved PP10 by 3.4% and TW by 2.3%. Thus the results of the current study are not consistent with studies in younger cohorts. The lack of improvement in PP10 & TW in the CT group may be a consequence of insufficient recovery between exercise training and testing. In particular, participants in all groups continued their endurance training at the completion of the 12 week program up until the date of testing. Therefore, if a stronger emphasis on taking more rest prior to testing had been incorporated, these values may have improved. Future research is warranted to better understand the effect of CT training and ST training on anaerobic performance in masters road cyclists.

In the present study, 12 weeks of either CT training or ST training did not significantly reduce MAP in the CT group. To date, no studies have investigated the effects of CT training or ST training on MAP in masters cyclists. However, the use of strength training to improve endurance cycling performance in healthy, younger and older adults is well supported (4, 19, 22). For example, Loveless et al. (22) reported 8 weeks of maximal leg-strength training significantly improved cycling peak aerobic power, in a group of healthy, younger males (n=7, 25.0 ± 2.0 years). Additionally, Izquierdo et al. (19) reported 16 weeks of progressive strength-training significantly increased cycling peak aerobic power in a group of healthy, older males (n=11, 64-74 years). In the present study, the ST group did not significantly improve MAP. No studies to date, have investigated the effects of sprint cycling training in masters cyclists. However, these results are in contrast to the findings from studies in younger cyclists, which have reported significant increases in MAP following sprint cycling training (20, 38). For example, Laursen et al. (20) reported a significant improvement in peak aerobic power following two weeks of sprint cycling training in a group of trained, younger cyclists (n=14, 23.5 ± 3.5 years). Unsurprisingly, the current study observed no significant change in MAP following the 12 week training period. These results suggest reducing cycling endurance training volume and replacing it with either CT training or ST training, does not negatively affect a primary marker of endurance performance in masters road cyclists.

In the present study 12 weeks of CT significantly improved TT (8.1%) in the CT group. Typical for road cycling competition is that a large group of riders are often together until the end of the race and the ability to sprint to the finish line determines their place in the race. Thus, sprinting speed is of particular importance to cycling performance. To date, no studies have investigated the effects of CT training on sprint cycling TT performance in masters cyclists. However, studies investigating the effects of concurrent strength and sprint running training have reported favourable effects on sprint running performance (9, 31). For example, Cristea et al. (9) reported a significant improvement in 60 meter sprint running time (2%) following 20 weeks of progressive strength training performed 4 times per week in a group of male masters sprint runners. In addition, Reaburn et al. (31) reported a significant improvement in 100 meter (4%) and 300 meter (2%) sprint running time following eight weeks of concurrent strength and sprint running training performed four times per week. Surprisingly, the ST group in the present study did not significantly improve TT performance. However the ST group, improved TT performance by 3.4%, which is similar to the reported improvements in sprint performance previously reported by Reaburn et al. (31) and Cristea et al. (9) in masters sprint runners following a period of progressive resistance training. Moreover, in the current study there were no differences in TT times between the CT group and ST group suggesting that the addition of strength training may not provide additional benefits to sprint cycling performance in masters road cyclists. Taken together, these results suggest 12 weeks of CT training significantly improves TT performance, which can benefit the masters road cyclists by improving sprint speed to the finish line.

6.6 Practical Applications

Previous research suggests masters cyclists face an age-related decline in lean mass, muscular strength and power, and sprinting performance. These declines may contribute to the age-related decline in competitive cycling performance, particularly the ability to accelerate rapidly or sprint to the finish line during a race. The results of the present study suggest that 12 weeks of CT training significantly improves lower body lean mass and sprint cycling time trial performance. However, in the ST group, only lower body lean mass improved with no changes seen in sprint TT performance. Based on the present findings, we recommend masters road cyclists undertake two additional strength training sessions for 12 weeks to improve lower limb lean mass and sprint cycling performance. Alternatively, masters road cyclists may prefer to undertake two additional sprint cycling sessions per week for 12 weeks, as another means of increasing lower limb lean mass. In the final analysis, the results of this study suggest adding a combination of strength and sprint cycling training to an existing endurance cycling program may limit the loss of lean mass with age and improve sprinting performance, but without compromising endurance performance in masters road cyclists

.

6.7 References

Alway SE, Coggan AR, Sproul MS, Abduljalil AM, Robitaille PM. Muscle torque in young and older untrained and endurance-trained men. *J Gerontol A Biol Sci Med Sci* 51: B195-B201, 1996.

Atkinson G, Davison R, Jeukendrup A, Passfield L. Science and cycling: current knowledge and future directions for research. *J Sports Sci* 21: 767-787, 2003.

Bastiaans J, Diemen A, Veneberg T, Jeukendrup A. The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. *Eur J Appl Physiol* 86: 79-84, 2001.

Bellamy LM, Joanisse S, Grubb A, Mitchell CJ, McKay BR, Phillips SM, Baker S, Parise G. The acute satellite cell response and skeletal muscle hypertrophy following resistance training. *PloS one* 9: e109739, 2014.

Cycling Australia 2015 Annual Report. (2015, September/October). Retrieved February 28, 2016 from http://www.cycling.org.au/Portals/10/CA_2015_AnnualReport_FINALemail.pdf

Cantrell GS, Schilling BK, Paquette MR, Murlasits Z. Maximal strength, power, and aerobic endurance adaptations to concurrent strength and sprint interval training. *Eur J Appl Physiol* 114: 763-771, 2014.

Churchward-Venne TA, Tieland M, Verdijk LB, Leenders M, Dirks ML, de Groot LC, Van Loon LJ. There are no nonresponders to resistance-type exercise training in older men and women. *J Am Med Dir Assoc* 16: 400-411, 2015.

Creer A, Ricard M, Conlee R, Hoyt G, Parcell A. Neural, metabolic and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *Int J Sports Med* 25: 92-98, 2004.

Cristea A, Korhonen M, Häkkinen K, Mero A, Alén M, Sipilä S, Viitasalo J, Koljonen M, Suominen H, Larsson L. Effects of combined strength and sprint training on regulation of muscle contraction at the whole-muscle and single-fibre levels in elite master sprinters. *Acta Physiol* 193: 275-289, 2008.

Del Vecchio L, Korhonen M, and Reaburn P. Lower limb muscular strength and power characteristics of masters road cyclists and age-matched sedentary adults. *Gazzetta Medica Italiana* Ahead of Print, 2016.

Fatouros I, Kambas A, Katrabasas I, Nikolaidis K, Chatzinikolaou A, Leontsini D, Taxildaris K. Strength training and detraining effects on muscular strength, anaerobic power, and mobility of inactive older men are intensity dependent. *Br J Sports Med* 39: 776-780, 2005.

Frontera WR, Meredith CN, O'Reilly KP, Evans WJ. Strength training and determinants of VO_2 max in older men. *J Appl Physiol* 68: 329-333, 1990.

Gent DN, Norton K. Aging has greater impact on anaerobic versus aerobic power in trained masters athletes. *J Sports Sci* 31: 97-103, 2013.

Häkkinen K, Alen M, Kraemer W, Gorostiaga E, Izquierdo M, Rusko H, Mikkola J, Häkkinen A, Valkeinen H, Kaarakainen E. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur J Appl Physiol* 89: 42-52, 2003.

Harridge S, Bottinelli R, Canepari M, Pellegrino M, Reggiani C, Esbjörnsson M, Balsom P, Saltin B. Sprint training, in vitro and in vivo muscle function, and myosin heavy chain expression. *J Appl Physiol* 84: 442-449, 1998.

Hawley JA, Noakes TD. Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. *Eur J Appl Physiol* 65: 79-83, 1992.

Heydari M, Freund J, Boutcher SH. The effect of high-intensity intermittent exercise on body composition of overweight young males. *Journal of Obesity* 2-8, 2012.

Hunter GR, McCarthy JP,Bamman MM. Effects of resistance training on older adults. *Sport Med* 34: 329-348, 2004.

Izquierdo M, Häkkinen K, Ibañez J, Antón A, Garrués M, Ruesta M,Gorostiaga EM. Effects of strength training on submaximal and maximal endurance performance capacity in middle-aged and older men. *J Strength Cond Res* 17: 129-139, 2003.

Laursen PB, Blanchard MA, Jenkins DG. Acute high-intensity interval training improves Tvent and peak power output in highly trained males. *Can J Appl Physiol* 27: 336-348, 2002.

Louis J, Hausswirth C, Easthope C, Brisswalter J. Strength training improves cycling efficiency in master endurance athletes. *Eur J Appl Physiol* 112: 631-640, 2012.

Loveless DJ, Weber CL, Haseler LJ, and Schneider DA. Maximal leg-strength training improves cycling economy in previously untrained men. *Med Sci Sports Exerc* 37: 1231, 2005.

Macgregor C, Reaburn P, Korhonen M. Training modalities of masters cyclists: An Australian study. Presented at Paper presented at European College of Sport Science 19th Annual Congress, Amsterdam, Holland, July 2-6, 2014.

Macpherson R, Hazell TJ, Olver TD, Paterson DH, Lemon P. Run sprint interval training improves aerobic performance but not maximal cardiac output. *Med Sci Sports Exerc* 43: 115-122, 2011.

Marcell TJ, Hawkins SA,Wiswell RA. Leg strength declines with advancing age despite habitual endurance exercise in active older adults. *J Strength Cond Res* 28: 504-513, 2014.

Mengelkoch LJ, Pollock ML, Limacher MC, Graves JE, Shireman RB, Riley WJ, Lowenthal DT, Leon AS. Effects of age, physical training, and physical fitness on coronary heart disease risk factors in older track athletes at twenty-year follow-up. *J Am Geriatr Soc* 45: 1446-1453, 1997.

Nederveen J, Joanisse S, Séguin C, Bell K, Baker S, Phillips S, Parise G. The effect of exercise mode on the acute response of satellite cells in old men. *Acta Physiol* 215: 177-190, 2015.

Norton K. Sports Medicine Australia pre-exercise screening system. *Sports Medicine Australia*, 2005.

Piacentini MF, De Ioannon G, Comotto S, Spedicato A, Vernillo G, and La Torre A. Concurrent strength and endurance training effects on running economy in master endurance runners. *J Strength Cond Res* 27: 2295-2303, 2013.

Reaburn P, Dascombe B. Endurance performance in masters athletes. *Eur Rev Aging Phys Act* 5: 31-42, 2008.

Reaburn P, Logan P, Mackinnon L. The Effect of Hypertrophy Resistance Training on Anaerobic Work Capacity in Veteran Sprint Runners. Canberra, Australia: Australian Sports Commission, 1994.

Rønnestad BR, Mujika I. Optimizing strength training for running and cycling endurance performance: A review. *Scand J Med Sci Sports* 24: 603-612, 2014.

Schell J, Leelarthaepin B. *Physical fitness assessment in exercise and sport science.* Leelar Biomediscience Services, 1990.

So RC, Ng JK-F, and Ng GY. Muscle recruitment pattern in cycling: a review. *Phys Ther Sport* 6: 89-96, 2005.

Staron R, Karapondo D, Kraemer W, Fry A, Gordon S, Falkel J, Hagerman F, Hikida R. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J Appl Physiol* 76: 1247-1255, 1994.

Stewart V, Saunders D, Greig C. Responsiveness of muscle size and strength to physical training in very elderly people: a systematic review. *Scand J Med Sci Sports* 24: 1-10, 2014.

Tanaka H, Seals D. Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms. *J Physiol* 586: 55-63, 2008.

Westgarth-Taylor C, Hawley JA, Rickard S, Myburgh KH, Noakes TD, Dennis SC. Metabolic and performance adaptations to interval training in endurance-trained cyclists. *Eur J Appl Physiol Occup Physiol* 75: 298-304, 1997.

Yamamoto LM, Klau JF, Casa DJ, Kraemer WJ, Armstrong LE, and Maresh CM. The effects of resistance training on road cycling performance among highly trained cyclists: a systematic review. *J Strength Cond Res* 24: 560-566, 2010.

Zajac A, Jarzabek R, and Waskiewicz Z. The siagnostic value of the 10-and 30-second wingate test for competitive athletes. *J Strength Cond Res* 13: 16-19, 1999.

7

Conclusions, Implications, and Future Research Directions

Previous research has shown the addition of a resistance training program to an established endurance running (Piacentini et al., 2013), endurance cycling (Louis, Hausswirth, Easthope, & Brisswalter, 2012) and sprint running training program (Cristea, 2008) improves performance in masters athletes . In addition, there is research evidence to suggest that both resistance training and sprint training offer cardiometabolic health benefits that may complement an established endurance training program in healthy older adults (Hagerman et al., 2000) and masters athletes (Kusy & Zielinski, 2015b) . However, no research to date has investigated the performance and/or health benefits of a concurrent resistance and sprint training program in masters road cyclists. The primary aim of the present thesis was to investigate the performance and health benefits of concurrent resistance and sprint cycling training in masters road cyclists.

The first peer-reviewed paper (Chapter 2) presented in the current thesis provided a synthesis of the relevant previous research that examined the effects of resistance training on endurance and sprint performance in masters athletes. The narrative literature review suggests resistance training interventions in masters athletes lead to improved sprint and endurance performance in older athletes. The actual event-specific performance changes demonstrate small but significant improvements 2-4 percent reductions in sprint running times and 3-6 percent improvements in both endurance cycling and running economy. Taken together, the limited data suggest resistance training programs undertaken by masters athletes produce positive effects on physiological determinants of sprint and endurance performance that are evidenced in enhanced sports performance in masters athletes. However, the review highlighted that further research was needed to design and deliver a resistance and sprint training program to improve sprint cycling performance in masters road cyclists.

Subsequent to the findings of Chapter 2, the aim of the second peer-reviewed paper (Chapter 3) was to develop and publish in a peer-reviewed journal a resistance and sprint cycling training program aimed at improving sprint cycling performance in masters road cyclists. Following an extensive review of the literature within this paper, it was determined that a concurrent resistance and sprint cycling training program aimed at improving sprint performance in masters road cyclists requires a mixed-methods resistance training design. Mixed-methods resistance training programs simultaneously train three dimensions of muscle characteristics - hypertrophy, maximal force production and maximal power output (Newton et al., 2002).

Previous research has shown mixed-methods resistance training programs effectively increase muscle mass, muscular strength and explosive force production in healthy older adults (Newton et al., 2002), masters sprint runners (Cristea et al., 2008) and masters endurance cyclists (Louis et al., 2012). Importantly, mixed-methods resistance training programs simultaneously train the three dimensions of muscle characteristics needed to attenuate age-related losses in muscle mass, muscular strength and muscular power that together affect sprint performance (Cristea et al., 2008). Taken together, the narrative literature review in press in *Strength and Conditioning Journal* presented a concurrent resistance and sprint cycling training program which incorporated a mixed-methods resistance training approach, designed to ttenuate the morphological changes associated with age which are known to affect sprint performance in masters athletes. However, the effect of a concurrent resistance and sprint cycling training program which incorporated mixed-methods resistance training on sprint performance in masters road cyclists had yet to be determined.

The findings from the above two peer-reviewed papers suggested the addition of both resistance and sprint cycling training is necessary for masters road cyclists to improve sprint cycling performance. However, valid and reliable assessments of changes in athletic performance was critical, particularly given that no studies to date had investigated the reliability of measures of explosive force production in masters athletes. Thus, the aim of the study presented in Chapter 4 was to investigate the test-retest reliability of the squat jump and countermovement jump power measures in masters road cyclists. It was hypothesised that masters athletes would display greater variability in squat jump and countermovement jump performance variables than younger athletes but that both squat jump and countermovement jump performance variables would meet acceptable test-rest reliability standards. The results of this peer-reviewed and published study demonstrated moderate to high intra-class correlations (0.56 to 0.95) for squat jump peak power with high intra-class correlations (>0.80) observed for countermovement jump performance measures including relative peak power (0.93) and relative peak force (0.94). In contrast, the coefficient of variation for squat jump performance measures ranged between 5.6 to 27.5 percent while the coefficient of variation for countermovement jump performance measures ranged from 3.9 to 27.5 percent. Taken together, the results of the study presented in Chapter 4 suggest the squat jump and countermovement jump tests provide reliable measures of explosive force production in masters athletes. However, due to age-related changes in intermuscular coordination patterns and neuromuscular function, variability of these measures in masters athletes may be greater than those reported in younger athletes.

Despite the widely known cardiometabolic benefits of endurance training in masters athletes (Hernelahti, Kujala, Kaprio, Karjalainen, & Sarna, 1998; Mengelkoch et al., 1997; Mikkelsen et al., 2013b), little is known about the potential cardiometabolic benefits of concurrent resistance and sprint training in the same cohort. Therefore, the aim of the fourth paper presented in the present thesis (Chapter 5) was to examine the effect of a concurrent resistance and sprint cycling training program on body composition and cardiometabolic risk factors in masters road cyclists. It was hypothesised that 12-weeks of concurrent resistance and sprint cycling training will improve body composition without negatively impacting cardiometabolic risk factors in masters road cyclists. The findings demonstrated that 12-weeks of concurrent resistance and sprint cycling training favourably affects body composition by lowering trunk fat mass and increasing lower limb lean mass without negatively affecting cardiometabolic health indicators in masters road cyclists. This finding suggests that replacing a portion of endurance training with concurrent resistance and sprint cycling training may positively affect body composition without negatively affecting cardiometabolic health indicators in masters road cyclists.

Having established the need for a concurrent resistance and sprint cycling training program to improve sprint performance in masters road cyclists (Chapters 2 and 3) and having determined the reliability of the squat and countermovement jump tests necessary for interpreting performance changes (Chapter 4), the aim of the final study (Chapter 6) was to examine the effect of a concurrent resistance and sprint cycling training program on sprint cycling performance in masters road cyclists. Two groups of masters road cyclists replaced two road-cycling sessions with two sprint cycling training sessions per week for 12-weeks (sprint cycling group) or four road-cycling sessions with two resistance and two sprint cycling training sessions per week for 12-weeks (concurrent resistance and sprint cycling group). All sprint cycling and resistance training sessions were monitored throughout the intervention period and performance testing conducted before and after the training period. It was hypothesised that 12-weeks of concurrent resistance and sprint training would significantly increase lean mass, muscular strength, muscular power and sprint cycling performance.

As hypothesised, the results showed 12-weeks of concurrent resistance and sprint cycling training led to significant increases in lower limb lean mass and improved sprint cycling performance in the masters road cyclists. In contrast, 12-weeks of sprint cycling training without the resistance training led to a significant increase in lower limb lean mass but no improvement in sprint cycling performance. Importantly, endurance cycling performance, as measured by peak aerobic power, was not significantly affected by the reduction in endurance training volume in either intervention group. Taken together, these results suggest replacing a portion of endurance training with a concurrent resistance and sprint cycling training program significantly increases the lower limb lean mass of masters road cyclists. However, improvements in sprint cycling performance in masters road cyclists may require the combination of both resistance and sprint cycling training.

7.1 Conclusion

The overall aim of this thesis was to examine both the performance and health benefits of concurrent resistance and sprint cycling training in masters road cyclists. It was hypothesised that 12-weeks of concurrent resistance and sprint-cycling training would result in (a) significant improvements in body composition without negatively impacting cardiometabolic risk factors; and (b) significant improvements in muscular strength, muscular power and sprint cycling performance in masters road cyclists. The results of the series of papers and studies presented in the present thesis suggest that concurrent resistance and sprint cycling training undertaken by masters road cyclists result in: (a) significant improvements in body composition without negatively impacting cardiometabolic risk factors; (b) and (c) significant improvements in sprint cycling performance. Specifically, substituting four endurance-training sessions with four resistance and sprint cycling training sessions per week resulted in a significant reduction in trunk fat mass with moderate effect sizes on systolic blood pressure, also suggesting concurrent resistance and sprint cycling training may have a favourable effect on blood pressure which is an important risk factor for cardiometabolic disease.

In addition to the above cardiometabolic health benefits, 12-weeks of concurrent resistance and sprint cycling training in masters road cyclists resulted in significant improvements in lower limb lean mass and sprint cycling performance without compromising endurance performance. Finally, we have demonstrated that squat jump and countermovement jump variables possess high test-retest reliability; however, in endurance-trained masters cyclists, peak force may be more reliably measured using the countermovement jump test, whereas peak power may be more reliably assessed using the SJ test. Thus, coaches and sports scientists should be cautious when selecting either the squat jump and countermovement jump test to assess peak power and peak force. Taken together, the thesis findings suggest that replacing a portion of road cycling training with concurrent resistance and sprint cycling training offers the masters road cyclist the ability to improve road-cycling performance by increasing lower limb lean mass and sprint cycling performance while also improving body composition without negatively impacting cardiometabolic risk factors.

7.2 Practical Implications

The present series of narrative reviews and investigations is the first to investigate the effects of concurrent resistance and sprint cycling training on cardiometabolic health indicators and sprint cycling performance in masters road cyclists. The findings provide detailed and evidence-based insights into how a concurrent resistance and sprint cycling training regime may be specifically applied for both health and performance outcomes in masters athletes as a cohort. For health practitioners, the findings show that concurrent resistance and sprint cycling training as a standalone intervention, or in addition to an established endurance exercise training regime, produces significant improvements in body composition and favourable reductions in systolic blood pressure that may lower cardiometabolic risk factors in masters road cyclists.

For sports scientists, strength and conditioning professionals and coaches working with masters road cyclists, the findings strongly suggest that lower limb lean muscle mass and sprint cycling performance can be improved with the inclusion of a 12-week concurrent resistance and sprint cycling training program. In order to optimise sprint cycling performance, a concurrent resistance and sprint cycling training program should be considered during a period of intensified training, such as the pre-competition phase of the road cycling season. Once this pre-competition phase is completed and the cyclists move into the competitive phase, both modes of training may be maintained with reductions in training volume and training frequency. For example, moving from two resistance and two sprint cycling training sessions per week in the pre-competition phase to one resistance training session and one sprint cycling training session per week. By substituting four road cycling training sessions per week with two resistance training sessions and two sprint cycling training sessions, the present thesis has shown that this approach to training leads to significant improvements in lower limb lean mass and sprint cycling performance without reducing peak endurance performance.

7.3 Future Directions

The findings presented in this thesis set a foundation for future research to further examine the use of concurrent resistance and sprint cycling training to improve both health and cycling performance outcomes in masters athletes as a cohort. Future research might:

- Use larger sample sizes and randomise participants into training groups from a range of other endurance sports, including running, swimming, rowing, and canoeing where both sprint and endurance performance are critical for performance.
- Monitor and assess sprint cycling performance with more accurate sprint cycling measurement devices such as electronic timing gates or cycling track timing systems.
- Investigate the effects of concurrent resistance and sprint cycling training on other markers of cardiometabolic health including fasting insulin levels, HDL- and LDL-cholesterol levels in both road cyclists and other cohorts of masters athletes.
- Compare and contrast the effects of indoor cycle ergometer-based sprint cycling training with normal cycling sprint training to determine if indoor cycling ergometry can increase lower limb lean mass and sprint cycling performance.

7.4 References

Aagaard, P., Suetta, C., Caserotti, P., Magnusson, S. P., & Kjær, M. (2010). Role of the nervous system in sarcopenia and muscle atrophy with aging: Strength training as a countermeasure. *Scandinavian Journal of Medicine & Science in Sports, 20*(1), 49-64.

Batista, C., & Soares, J. M. (2013). Are former elite athletes more protected against metabolic syndrome? *Journal of Cardiology, 61*(6), 440-445.

Bell, K. E., Séguin, C., Parise, G., Baker, S. K., & Phillips, S. M. (2015). Day-to-day changes in muscle protein synthesis in recovery from resistance, aerobic, and high-intensity interval exercise in older men. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 70*(8), 1024-1029.

Brisswalter, J., & Nosaka, K. (2013). Neuromuscular factors associated with decline in long-distance running performance in master athletes. *Sports Medicine, 43*(1), 51-63.

Bruseghini, P., Calabria, E., Tam, E., Milanese, C., Oliboni, E., Pezzato, A., Mucelli, R. P. (2015). Effects of eight weeks of aerobic interval training and of isoinertial resistance training on risk factors of cardiometabolic diseases and exercise capacity in healthy elderly subjects. *Oncotarget, 6*(19), 16998-7015.

Buyukyazi, G. (2005). Differences in blood lipids and apolipoproteins between master athletes, recreational athletes and sedentary men. *Journal of Sports Medicine and Physical Fitness, 45*(1), 112.

Churchward-Venne, T. A., Tieland, M., Verdijk, L. B., Leenders, M., Dirks, M. L., de Groot, L. C., & van Loon, L. J. (2015). There are no nonresponders to resistance-type exercise training in older men and women. *Journal of the American Medical Directors Association, 16*(5), 400-411.

Cristea, A. (2008). *Effects of ageing and physical activity on regulation of muscle contraction*. (Doctoral Thesis). Acta Universitatis Upsaliensis, Upsaliensis.

Cristea, A., Korhonen, M., Häkkinen, K., Mero, A., Alén, M., Sipilä, S., Larsson, L. (2008). Effects of combined strength and sprint training on regulation of muscle contraction at the whole muscle and single fibre levels in elite master sprinters. *Acta Physiologica, 193*(3), 275-289.

Cycling Australia. (2016). Cycling Australia annual reports. Retrived from: http://www.cycling.org.au/Home/About-CA/Annual-Reports

Del Vecchio, L., Korhonen, M. T., & Reaburn, P. (2016). The effects of resistance training on sprint running and sprint cycling performance in masters athletes: A narrative review. *Journal of Fitness Research,* 5(1), 5-13.

Dey, S. K., Ghosh, C., Debray, P., & Chatterjee, M. (2002). Coronary artery disease risk factors & their association with physical activity in older athletes. *Journal of Cardiovascular Risk, 9*(6), 383-392.

Drenowatz, C., Sui, X., Fritz, S., Lavie, C. J., Beattie, P. F., Church, T. S., & Blair, S. N. (2015). The association between resistance exercise and cardiovascular disease risk in women. *Journal of Science and Medicine in Sport, 18*(6), 632-636.

Drey, M., Sieber, C. C., Degens, H., McPhee, J., Korhonen, M. T., Müller, K., Rittweger, J. (2016). Relation between muscle mass, motor units and type of training in master athletes. *Clinical Physiology and Functional Imaging, 36*(1), 70-76.

Gava, P., Kern, H., & Carraro, U. (2015). Age-associated power decline from running, jumping, and throwing male masters world records. *Experimental Aging Research, 41*(2), 115-135.

Hagerman, F., Walsh, S., Staron, R., Hikida, R., Gilders, R., Murrary, T., & Ragg, K. (2000). Effects of high-intensity resistance training on untrained older men. I. Strength, cardiovascular, and metabolic responses. *The Journals of Gerontolology Series: A, Biological Sciences and Medical Sciences, 55*(7), B336-B346.

Hajkowicz, S., Cook, H., Wilhelmseder, L., & Boughen, N. (2013). The future of Australian sport: Megatrends shaping the sports sector over coming decades. A consultancy report for the Australian sports commission: CSIRO, Australia.

Häkkinen, K., Kallinen, M., Izquierdo, M., Jokelainen, K., Lassila, H., Mälkiä, E., Alen, M. (1998). Changes in agonist-antagonist EMG muscle CSA, and force during strength training in middle-aged and older people. *Journal of Applied Physiology, 84*(4), 1341-1349.

Hayes, L. D., Grace, F. M., Sculthorpe, N., Herbert, P., Kilduff, L. P., & Baker, J. S. (2013). Does chronic exercise attenuate age-related physiological decline in males? *Research in Sports Medicine, 21*(4), 343-354.

Hernelahti, M., Kujala, U. M., Kaprio, J., Karjalainen, J., & Sarna, S. (1998). Hypertension in master endurance athletes. *Journal of Hypertension, 16*(11), 1573-1577.

International Masters Games Association. (2016). Previous masters events. Retrieved from: https://imga.ch/en/events/#previousevents

Kessler, H. S., Sisson, S. B., & Short, K. R. (2012). The potential for high-intensity interval training to reduce cardiometabolic disease risk. *Sports Medicine, 42*(6), 489-509.

Kettunen, J. A., Kujala, U. M., Kaprio, J., & Sarna, S. (2006). Health of master track and field athletes: A 16-year follow-up study. *Clinical Journal of Sport Medicine, 16*(2), 142-148.

Kim, T. N., & Choi, K. M. (2015). The implications of sarcopenia and sarcopenic obesity on cardiometabolic disease. *Journal of Cellular Biochemistry, 116*(7), 1171-1178.

Korhonen, M. T., Cristea, A., Alén, M., Häkkinen, K., Sipilä, S., Mero, A., Suominen, H. (2006). Aging, muscle fiber type, and contractile function in sprint-trained athletes. *Journal of Applied Physiology, 101*(3), 906-917.

Korhonen, M. T., Mero, A., & Suominen, H. (2003). Age-related differences in 100-m sprint performance in male and female master runners. *Medicine and Science in Sports and Exercise, 35*(8), 1419-1428.

Kusy, K., & Zielinski, J. (2015). Sprinters versus long-distance runners: How to grow old healthy. *Exercise and Sport Sciences Reviews, 43*(1), 57-64.

Kusy, K., Zieliński, J., & Pilaczyńska-Szcześniak, Ł. (2013). Insulin sensitivity and β-cell function estimated by homa2 model in sprint-trained athletes aged 20− 90 years vs endurance runners and untrained participants. *Journal of Sports Sciences, 31*(15), 1656-1664.

LaChausse, R. G. (2006). Motives of competitive and non-competitive cyclists. *Journal of Sport Behavior, 29*(4), 304.

Lanza, I. R., Short, D. K., Short, K. R., Raghavakaimal, S., Basu, R., Joyner, M. J., Nair, K. S. (2008). Endurance exercise as a countermeasure for aging. *Diabetes, 57*(11), 2933-2942.

Leenders, M., Verdijk, L. B., van der Hoeven, L., van Kranenburg, J., Nilwik, R., & van Loon, L. J. (2013). Elderly men and women benefit equally from prolonged resistance-type exercise training. *The Journals of Gerontolology Series: A, Biological Sciences and Medical Sciences, 68*(7), 769-779.

Leong, B., Kamen, G., Patten, C., & Burke, J. R. (1999). Maximal motor unit discharge rates in the quadriceps muscles of older weight lifters. *Medicine and Science in Sports and Exercise, 31*(11), 1638-1644.

Lepers, R., Sultana, F., Thierry, B., Hausswirth, C., & Brisswalter, J. (2009). Age-related changes in triathlon performance. *International Journal of Sports Medicine, 30*, 1-6.

Louis, J., Hausswirth, C., Easthope, C., & Brisswalter, J. (2012). Strength training improves cycling efficiency in master endurance athletes. *European Journal of Applied Physiology, 112*(2), 631-640.

Lynch, N. A., Ryan, A. S., Evans, J., Katzel, L. I., & Goldberg, A. P. (2007). Older elite football players have reduced cardiac and osteoporosis risk factors. *Medicine and Science in Sports and Exercise, 39*(7), 1124-1130.

Marti, B., Knobloch, M., Riesen, W. F., & Howald, H. (1991). Fifteen-year changes in exercise, aerobic power, abdominal fat, and serum lipids in runners and controls. *Medicine and Science in Sports and Exercise*, *23*(1), 115-122.

Martin, J., Farrar, R., Wagner, B., & Spirduso, W. (2000). Maximal power across the lifespan. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55*(6), M311-M316.

Mengelkoch, L. J., Pollock, M. L., Limacher, M. C., Graves, J. E., Shireman, R. B., Riley, W. J., Leon, A. S. (1997). Effects of age, physical training, and physical fitness on coronary heart disease risk factors in older track athletes at twenty-year follow-up. *Journal of the American Geriatrics Society, 45*(12), 1446-1453.

Mikkelsen, U., Couppe, C., Karlsen, A., Grosset, J., Schjerling, P., Mackey, A., Kjær, M. (2013). Life-long endurance exercise in humans: circulating levels of inflammatory markers and leg muscle size. *Mechanisms of Ageing and Development, 134*(11), 531-540.

Nederveen, J., Joanisse, S., Séguin, C., Bell, K., Baker, S., Phillips, S., & Parise, G. (2015). The effect of exercise mode on the acute response of satellite cells in old men. *Acta Physiologica, 215*(4), 177-190.

Newton, R. U., Hakkinen, K., Hakkinen, A., McCormick, M., Volek, J., & Kraemer, W. J. (2002). Mixed-methods resistance training increases power and strength of young and older men. *Medicine and Science in Sports and Exercise, 34*(8), 1367-1375.

Nilwik, R., Snijders, T., Leenders, M., Groen, B. B., van Kranenburg, J., Verdijk, L. B., & van Loon, L. J. (2013). The decline in skeletal muscle mass with aging is mainly attributed to a reduction in type II muscle fiber size. *Experimental Gerontology, 48*(5), 492-498.

Nowak, A., Straburzyńska-Lupa, A., Kusy, K., Zieliński, J., Felsenberg, D., Rittweger, J., Pilaczyńska-Szcześniak, Ł. (2010). Bone mineral density and bone turnover in male masters athletes aged 40–64. *The Aging Male, 13*(2), 133-141.

Park, Y.-M. M., Sui, X., Liu, J., Zhou, H., Kokkinos, P. F., Lavie, C. J., Blair, S. N. (2015). The effect of cardiorespiratory fitness on age-related lipids and lipoproteins. *Journal of the American College of Cardiology, 65*(19), 2091-2100.

Parto, P., Lavie, C. J., Swift, D., & Sui, X. (2015). The role of cardiorespiratory fitness on plasma lipid levels. *Expert Review of Cardiovascular Therapy, 13*(11), 1177-1183.

Phillips, S. A., Mahmoud, A. M., Brown, M. D., & Haus, J. M. (2015). Exercise interventions and peripheral arterial function: Implications for cardio-metabolic disease. *Progress in Cardiovascular Diseases, 57*(5), 521-534.

Piacentini, M. F., De Ioannon, G., Comotto, S., Spedicato, A., Vernillo, G., & La Torre, A. (2013). Concurrent strength and endurance training effects on running economy in master endurance runners. *The Journal of Strength & Conditioning Research, 27*(8), 2295-2303.

Randers, M. B., Andersen, J. L., Petersen, J., Sundstrup, E., Jakobsen, M. D., Bangsbo, J., Krustrup, P. (2014). Exercise performance and cardiovascular health variables in 70-year-old male soccer players compared to endurance-trained, strength-trained and untrained age-matched men. *Journal of Sports Sciences, 32*(13), 1300-1308.

Reaburn, P., & Dascombe, B. (2008). Endurance performance in masters athletes. *European Review of Aging and Physical Activity*, *5*(1), 31-42.

Reaburn, P., Logan, P., & Mackinnon, L. (1994). The effect of hypertrophy resistance training on anaerobic work capacity in veteran sprint runners*. Australian Sports Commission*. Retrieved from: https://www.clearinghouseforsport.gov.au/__data/assets/pdf_file/0006/198375/RP1996summary.pdf

Reid, K. F., Martin, K. I., Doros, G., Clark, D. J., Hau, C., Patten, C., Fielding, R. A. (2015). Comparative effects of light or heavy resistance power training for improving lower extremity power and physical performance in mobility-limited older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *70*(3), 372-378.

Rønnestad, B. R., Hansen, E. A., & Raastad, T. (2010). Effect of heavy strength training on thigh muscle cross-sectional area, performance determinants and performance in well-trained cyclists. *European Journal of Applied Physiology, 108*(5), 965-975.

Scanlon, T. C., Fragala, M. S., Stout, J. R., Emerson, N. S., Beyer, K. S., Oliveira, L. P., & Hoffman, J. R. (2014). Muscle architecture and strength: Adaptations to short-term resistance training in older adults. *Muscle & Nerve, 49*(4), 584-592.

Stiefel, M., Knechtle, B., & Lepers, R. (2014). Master triathletes have not reached limits in their ironman triathlon performance. *Scandinavian Journal of Medicine & Science in Sports*, *24*(1), 89-97.

Suominen, H. (2011). Ageing and maximal physical performance. *European Review of Aging and Physical Activity, 8*(1), 37-42.

Tanaka, H., & Seals, D. R. (2008). Endurance exercise performance in masters athletes: Age-associated changes and underlying physiological mechanisms. *The Journal of Physiology, 586*(1), 55-63.

Thomas, G. N., Hong, A. W., Tomlinson, B., Lau, E., Lam, C. W., Sanderson, J. E., & Woo, J. (2005). Effects of tai chi and resistance training on cardiovascular risk factors in elderly chinese subjects: A 12-month longitudinal, randomized, controlled intervention study. *Clinical Endocrinology*, *63*(6), 663-669.

Vechin, F. C., Libardi, C. A., Conceição, M. S., Damas, F. R., Lixandrão, M. E., Berton, R. P., Chacon-Mikahil, M. P. T. (2015). Comparisons between low-intensity resistance training with blood flow restriction and high-intensity resistance training on quadriceps muscle mass and strength in the elderly. *The Journal of Strength & Conditioning Research, 29*(4), 1071-1076.

Young, W. B. (2006). Transfer of strength and power training to sports performance. *International Journal of Sports Physiology and Performance, 1*(2), 74.

Zampieri, S., Pietrangelo, L., Loefler, S., Fruhmann, H., Vogelauer, M., Burggraf, S., Sedliak, M. (2015). Lifelong physical exercise delays age-associated skeletal muscle decline. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *70*(2), 163-173.

Appendices

Appendix A

Ethical Approval, Participant Information Sheets, Consent forms

Ethical Approval Letter – 2014

Ethical Amendment Approval Letter – 2015

Participant Information Sheet – Study one – Chapter 4

Consent Form – Study one – Chapter 4

Participant Information Sheet – Study two – Chapter 5

Consent Form – Study one – Chapter 5

Participant Information Sheet – Study three – Chapter 6

Consent Form – Study one – Chapter 6

CQUniversity AUSTRALIA

27th July 2015

Dear A/Prof Reaburn and Mr Delvecchio

HUMAN RESEARCH ETHICS COMMITTEE OUTCOME PROJECT: H14/07-162, *EFFECT OF CONCURRENT STRENGTH AND CYCLE SPRINT TRAINING ON SPRINT CYCLING PERFORMANCE, MUSCLE MORPHOLOGY AND NEUROMUSCULAR FACTORS IN VETERAN CYCLISTS*

The Human Research Ethics sCommittee is an approved institutional ethics committee constituted in accord with guidelines formulated by the National Health and Medical Research Council (NHMRC) and governed by policies and procedures consistent with principles as contained in publications such as the joint Universities Australia and NHMRC *Australian Code for the Responsible Conduct of Research.* This is available at http://www.nhmrc.gov.au/publications/synopses/_files/r39.pdf.

On 29 July 2014, the committee met and considered your application. The project was assessed as being greater than low risk, as defined in the National Statement. On 12 August 2014, the committee acknowledged compliance with the revisions requested to be made to your research project *Effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists* (Project Number H14/07-162) and it is now **APPROVED**. On 23

July 2015, the Chair approved your request to modify the project to include 2 reliability measures, and to extend the data collection dates.

The period of ethics approval will now be from 12 August 2014 to 1 December 2015. The approval number is H14/07-162; please quote this number in all dealings with the Committee. HREC wishes you well with the undertaking of the project and looks forward to receiving the final report and statement of findings.

The standard conditions of approval for this research project are that:

a. you conduct the research project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments required to be made to the proposal by the Human Research Ethics Committee;

b. you advise the Human Research Ethics Committee (email ethics@cqu.edu.au) immediately if any complaints are made, or expressions of concern are raised, or any other issue in relation to the project which may warrant review of ethics approval of the project. *(A written report detailing the adverse occurrence or unforeseen event must be submitted to the Committee Chair within one working day after the event.)*

c. you make submission to the Human Research Ethics Committee for approval of any proposed variations or modifications to the approved project before making any such changes;

d. you provide the Human Research Ethics Committee with a written "Annual Report" on each anniversary date of approval (for projects of greater than 12 months) and "Final Report" by no later than one (1) month after the approval expiry date; *(A copy of the reporting pro formas may be obtained from the Human Research Ethics Committee Secretary, Sue Evans please contact at the telephone or email given on the first page.)*

e. you accept that the Human Research Ethics Committee reserves the right to conduct scheduled or random inspections to confirm that the project is being conducted in accordance to its approval. Inspections may include asking questions of the research team, inspecting all consent documents and records and being guided through any physical experiments associated with the project.

f. if the research project is discontinued, you advise the Committee in writing within five (5) working days of the discontinuation;

g. A copy of the Statement of Findings is provided to the Human Research Ethics Committee when it is forwarded to participants.

Please note that failure to comply with the conditions of approval and the *National Statement on Ethical Conduct in Human Research* may result in withdrawal of approval for the project.

The Human Research Ethics Committee is committed to supporting researchers in achieving positive research outcomes through sound ethical research projects. If you have issues where the Human Research Ethics Committee may be of assistance or have any queries in relation to this approval please do not hesitate to contact the Ethics and Compliance Officer or myself.

Yours sincerely,

[redacted]

Dr Tania Signal
Chair, Human Research Ethics Committee

Cc: Dr Marko Korhonen (co-supervisor) Project file

APPROVED

Office of Research

CQUniversity AUSTRALIA

12th August 2014

Dear A/Prof Reaburn and Mr Delvecchio

HUMAN RESEARCH ETHICS COMMITTEE OUTCOME PROJECT: H14/07-162, *EFFECT OF CONCURRENT STRENGTH AND CYCLE SPRINT TRAINING ON SPRINT CYCLING PERFORMANCE, MUSCLE MORPHOLOGY AND NEUROMUSCULAR FACTORS IN VETERAN CYCLISTS*

The Human Research Ethics Committee is an approved institutional ethics committee constituted in accord with guidelines formulated by the National Health and Medical Research Council (NHMRC) and governed by policies and procedures consistent with principles as contained in publications such as the joint Universities Australia and NHMRC *Australian Code for the Responsible Conduct of Research.* This is available at http://www.nhmrc.gov.au/publications/synopses/_files/r39.pdf.

On 29 July 2014, the committee met and considered your application. The project was assessed as being greater than low risk, as defined in the National Statement. On 12 August 2014, the committee acknowledged compliance with the revisions requested to be made to your research project *Effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists* (Project Number H14/07-162) and it is now **APPROVED**.

The period of ethics approval will be from 12 August 2014 to 1 July 2015. The approval number is H14/07-162; please quote this number in all dealings with the Committee. HREC wishes you well with the undertaking of the project and looks forward to receiving the final report and statement of findings.

The standard conditions of approval for this research project are that:

a. you conduct the research project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments required to be made to the proposal by the Human Research Ethics Committee;

b. you advise the Human Research Ethics Committee (email ethics@cqu.edu.au) immediately if any complaints are made, or expressions of concern are raised, or any other issue in relation to the project which may warrant review of ethics approval of the project. *(A written report detailing the adverse occurrence or unforeseen event must be submitted to the Committee Chair within one working day after the event.)*

- **c.** you make submission to the Human Research Ethics Committee for approval of any proposed variations or modifications to the approved project before making any such changes;
- **d.** you provide the Human Research Ethics Committee with a written “Annual Report” on each anniversary date of approval (for projects of greater than 12 months) and “Final Report” by no later than one (1) month after the approval expiry date; (*A copy of the reporting pro formas may be obtained from the Human Research Ethics Committee Secretary, Sue Evans please contact at the telephone or email given on the first page.)*
- **e.** you accept that the Human Research Ethics Committee reserves the right to conduct scheduled or random inspections to confirm that the project is being conducted in accordance to its approval. Inspections may include asking questions of the research team, inspecting all consent documents and records and being guided through any physical experiments associated with the project.
- **f.** if the research project is discontinued, you advise the Committee in writing within five (5) working days of the discontinuation;
- **g.** A copy of the Statement of Findings is provided to the Human Research Ethics Committee when it is forwarded to participants.

Please note that failure to comply with the conditions of approval and the *National Statement on Ethical Conduct in Human Research* may result in withdrawal of approval for the project.

The Human Research Ethics Committee is committed to supporting researchers in achieving positive research outcomes through sound ethical research projects. If you have issues where the Human Research Ethics Committee may be of assistance or have any queries in relation to this approval please do not hesitate to contact the Ethics and Compliance Officer or myself.

Yours sincerely,

[redacted]

Dr Tania Signal

Chair, Human Research Ethics Committee

Cc: Dr Marko Korhonen (co-supervisor) Project file

Reliability of squat jump and countermovement jump performance in masters athletes

Information Sheet

Project Overview

Reliable methods of assessing lower limb explosive power are crucial to developing exercise programs which are effective at improving sports performance and providing accurate feedback to athletes and coaches. Two commonly performed tests conducted in the Exercise and Sports Science domain are the squat jump and countermovement test's. Given the widespread use these tests and the increasing interest in resistance training interventions in healthy older adults and masters athletes alike, awareness of the variability that may exist within these tests is crucial to be albe to discriminate between random erro and real differences as a result of a resistance training interventions. Therefore, the aim of this project is to test the test-retest reliability of the squat jump and countermovement jump tests.

Participation Procedure

If you agree to participate you will be asked to attend one (2) data collection session lasting approximately one hour. You will be asked questions about your health to screen for health or injury concerns which may exclude you from the study. You will have your body weight and height measured. After a brief warm up,. You will then perform three (3) squat jumps attempts on a force plate, separated by two (2) minutes rest. Following this procedure, you will then be asked to perform (3) countermovement jump attempts on a force plate, also separated by (2) minutes of rest. You will be asked to jump as high as you can each time.

Benefits and Risks

There is a small risk of musculoskeletal injury associated with the performance of the squat jump and countermovement jump tests. The likelihood and severity of this is low and no incidences of injury have been reported in our laboratory in the past 10 years. These procedures are no more demanding than usual physical activity or sports participation. You will be screened for injury or medical conditions prior to participation using the Australian Pre-Exercise Screening System. You will complete an appropriate warm-up procedure prior to testing. All testing sessions will be supervised by Accredited Exercise Physiologist with significant experience in performance of these tests. There may be no immediate benefit to you. However, the findings from this study will provide information which will assist the exercise and sports science community in determining the reliability of measures of lower limb explosive power.

We believe the potential benefits regarding the validation of testing methods significantly outweigh the risks associated with this project. If you have any concerns regarding these or other risks prior to, during, or after the study, these may be directed to the CQUniversity Ethics Committee (contact details provided below).

Confidentiality

Upon arrival participants will be linked to their assigned code. This will be done to allow the research team to provide each participant with individual feedback regarding the results of the research. Examples: information regarding muscular power, strength, anaerobic performance, sprint cycling performance and training information. Participants will provide their name and contact details on a coded informed consent form. This code will be transferred to the data collection sheet. These codes will be added to a spreadsheet that is password protected on the computers of the chief investigator. Informed consent forms and data collection sheets will be stored separately in a locked cabinet in the office of the chief investigator. Physical data will be downloaded to a computer program and the files back up on a password protected server.

Outcomes

Research outcomes will be disseminated by a variety of means including general written reports for media, academic publications in a PhD thesis, and as individual reports for the participants.

Consent

Consent will be given completely out of the participant's free will and there will be no consequences for non-participation or for withdrawal from the study.

Feedback

All feedback will be given to participants in report form and explanation can be given through private consultation or over the phone by one of the principal investigators, depending on the participant's preferences.

Questions/Further information

For any queries or for any further information please do not hesitate to contact Luke Delvecchio:

[redacted]
l.delvecchio@cqu.edu.au

Concerns or complaints

If you have any concerns or complaints about the nature and/or conduct of this research project please contact CQUniversity's Office of Research (Tel: 07 4923 2603; Email: ethics@cqu.edu.au; Mailing address: Building 32, CQUniversity, Rockhampton QLD 4702)

CQUniversity AUSTRALIA

Reliability of squat jump and countermovement jump performance in masters athletes

Consent Form

I consent to participation in this research project (The effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists) and agree that:

36. An Information Sheet has been provided to me that I have read and fully understood.
37. Any questions I had about the project have been answered to my satisfaction by the Information Sheet and further verbal explanations.
38. I understand that my participation or non-participation in the research project will not affect my medical care.
39. I understand that I have the right to withdraw from the project at any time for any reason without penalty or prejudice.
40. I understand the pooled research findings will be included in the researcher’s publication(s) on the project (The effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists). Project results may be presented at conferences, and may appear in journal articles and in a PhD thesis.
41. I understand that to preserve anonymity and maintain confidentiality of participants, a research ID number will be assigned to each participant and that all data collected will be carefully stored in a secure location in a manner that keeps all personal information confidential.
42. I am aware that a Plain English statement of results will be available to participants following the analysis of all study-related results.
43. I agree that I am providing informed consent to participate in this project (Reliability of squat jump and countermovement jump performance in masters).

Signature:

____

Date:

____

Name (please print):

____

Witness:

____

Witness Date:

____

Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists

Information Sheet

Project Overview

The purpose of this study will be to determine if replacing a portion of endurance training with combined resistance and sprint training or sprint training alone will negatively affect cardiometabolic health indicators in masters endurance cyclists. This study will add to the growing body of research in Masters athletes and therefore will also assist current Masters athletes, coaches and researchers in understanding the potential health benefits of concurrent resistance and sprint cycling training .

Participation Procedure

If you agree to participate you will be asked to attend two sessions at the exercise and sport science laboratory in building 81 at CQUniversity, to obtain baseline anthropometric data (height and weight). Health measurements will include: muscle mass, fat mass, blood lipids including: high density Lipoprotein (HDL) and triglycerides (TG), Capillary blood sampling (finger prick to obtain blood, how people check blood lactate): During the finger stick blood collection sterile 28 or 30 gauge lancets will be inserted into the distal end (near the finger tip) of any finger of either hand to acquire approximately 25 μL of capillary blood which will be drawn for measures of high density Lipoprotein (HDL), and triglycerides (TG). Finally, resting blood pressure will be measured using automatic calibrated blood pressure monitor. A Dual-energy X-ray absorptiometry (DEXA) scan will measure and assess both muscle mass and fat mas. Two days after completing the health testing, participants will return to measure $VO_{2\ peak}$, at cessation of exercise each participant will remain in the laboratory for 2 hours for observation while heart rate, oxygen consumption and lactate levels return to normal.

Benefits

Participants will have physical data recorded and provided as feedback. This information can be used to compare to previous data to show if current training practices are demonstrating performance benefits. If the participants have not undergone physical testing before they will be educated about how to use the information obtained to maximise their training practices to realise their best physical performance. Specifically, participants stand to gain information on:

- Health Parameters, such as: blood pressure, cholesterol, triglycerides and body composition (% body fat and muscle mass).
- Physical performance characteristics, such as: $VO_{2\ peak}$
- How to correctly and safely use weight training to increase muscle size, muscle strength, muscle power and to improve sporting performance

Risks

Participants will be exposed to minimal risk during this study. Possible risks include maximal exercise testing and blood sampling via capillary (finger prick) and venepuncture. Risks will be minimised through thorough medical screening of all participants and all blood samples will be taken by a trained phlebotomist.

Confidentiality

Upon arrival participants will be linked to their assigned code. This will be done to allow the research team to provide each participant with individual feedback regarding the results of the research. Examples: information regarding muscular power, strength, anaerobic performance, sprint cycling performance and training information. Participants will provide their name and contact details on a coded informed consent form. This code will be transferred to the data collection sheet. These codes will be added to a spreadsheet that is password protected on the computers of the chief investigator. Informed consent forms and data collection sheets will be stored separately in a locked cabinet in the office of the chief investigator. Physical data will be downloaded to a computer program and the files backed up on a password protected server.

Outcomes

Research outcomes will be disseminated by a variety of means including general written reports for media, academic publications in a PhD thesis, and as individual reports for the participants.

Consent

Consent will be given completely out of the participant's free will and there will be no consequences for non-participation or for withdrawal from the study.

Feedback

All feedback will be given to participants in report form and explanation can be given through private consultation or over the phone by one of the principal investigators, depending on the participant's preferences.

Questions/Further information

For any queries or for any further information please do not hesitate to contact Luke Delvecchio:

[redacted]
l.delvecchio@cqu.edu.au

Concerns or complaints

If you have any concerns or complaints about the nature and/or conduct of this research project please contact CQUniversity's Office of Research (Tel: 07 4923 2603; Email: ethics@cqu.edu.au; Mailing address: Building 32, CQUniversity, Rockhampton QLD 4702)

Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists

Consent Form

I consent to participation in this research project (The effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists) and agree that:

1. An Information Sheet has been provided to me that I have read and fully understood.
2. Any questions I had about the project have been answered to my satisfaction by the Information Sheet and further verbal explanations.
3. I understand that my participation or non-participation in the research project will not affect my medical care.
4. I understand that I have the right to withdraw from the project at any time for any reason without penalty or prejudice.
5. I understand the pooled research findings will be included in the researcher's publication(s) on the project (The effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists). Project results may be presented at conferences, and may appear in journal articles and in a PhD thesis.
6. I understand that to preserve anonymity and maintain confidentiality of participants, a research ID number will be assigned to each participant and that all data collected will be carefully stored in a secure location in a manner that keeps all personal information confidential.
7. I am aware that a Plain English statement of results will be available to participants following the analysis of all study-related results.
8. I agree that I am providing informed consent to participate in this project (Effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists).

Signature:

____

Date:

____

Name (please print):

____

Witness:

____

Witness Date:

____

Effects of Concurrent Strength and Sprint Training on Lean Mass, Strength, Power and Sprint Performance in Masters Road Cyclists

Information Sheet

Project Overview

The purpose of this study will be to examine the effect of concurrent resistance and sprint cycling training on both sprint cycling performance and the common age-related declines in morphology and physiology of aging athletes. This study will add to the growing body of research in Masters athletes and therefore will also assist current Masters athletes, coaches and researchers in improving compliance, and sprint cycling performance leading to greater participation in a high level of organised sport in older adults.

Participation Procedure

If you agree to participate you will be asked to attend two sessions at the exercise and sport science laboratory in building 81 at CQUniversity for two testing sessions at the exercise and sport science laboratory in building 81 at CQUniversity (separated by at least two days). To obtain baseline anthropometric data height and weight. A Dual-energy X-ray absorptiometry (DEXA) scan will measure and assess both muscle mass and fat mass, a DEXA scan is a standard procedure that has limited radiation. This test will be undertaken. The Dexa Scan will be performed by a Certified Clinical Densitometrist. Two days after completing the health testing, participants will return to undertake neuromuscular, dynamic strength and anaerobic performance testing. Performance measures will include neuromuscular power, dynamic strength, cycling peak power and total work capacity, at cessation of exercise each participant will remain in the laboratory for 2 hours for observation while heart rate, oxygen consumption and lactate levels return to normal. Two days after the Neuromuscular, dynamic strength and anaerobic performance testing, participants will attend the Rockhampton cycling velodrome to perform 200-m sprint time-trials, here the participants will perform, three timed 200-meter cycling sprints.

Benefits

Participants will have physical data recorded and provided as feedback. This information can be used to compare to previous data to show if current training practices are demonstrating performance benefits. If the participants have not undergone physical testing before they will be educated how to use the information obtained to maximise their training practices to realise their best physical performance. Specifically, participants stand to gain information on:

- Health Parameters, such as: blood pressure, cholesterol, triglycerides and body composition (% body fat and muscle mass).
- Physical performance characteristics, such as: Muscle strength, muscle power, cycling power, and 200-meter sprint cycling performance.
- How to correctly and safely use weight training to increase muscle size, muscle strength, muscle power and to improve sporting performance

Risks

Participants will be exposed to minimal risk during this study. Possible risks include maximal exercise testing and blood sampling via capillary (finger prick) and venepuncture. Risks will be minimised through thorough medical screening of all participants and all blood samples will be taken by a trained phlebotomist.

Confidentiality

Upon arrival participants will be linked to their assigned code. This will be done to allow the research team to provide each participant with individual feedback regarding the results of the research. Examples: information regarding muscular power, strength, anaerobic performance, sprint cycling performance and training information. Participants will provide their name and contact details on a coded informed consent form. This code will be transferred to the data collection sheet. These codes will be added to a spreadsheet that is password protected on the computers of the chief investigator. Informed consent forms and data collection sheets will be stored separately in a locked cabinet in the office of the chief investigator. Physical data will be downloaded to a computer program and the files back up on a password protected server.

Outcomes

Research outcomes will be disseminated by a variety of means including general written reports for media, academic publications in a PhD thesis, and as individual reports for the participants.

Consent

Consent will be given completely out of the participant’s free will and there will be no consequences for non-participation or for withdrawal from the study.

Feedback

All feedback will be given to participants in report form and explanation can be given through private consultation or over the phone by one of the principal investigators, depending on the participant’s preferences.

Questions/Further information

For any queries or for any further information please do not hesitate to contact Luke Delvecchio:

[redacted]
l.delvecchio@cqu.edu.au

Concerns or complaints

If you have any concerns or complaints about the nature and/or conduct of this research project please contact CQUniversity's Office of Research (Tel: 07 4923 2603; Email: ethics@cqu.edu.au; Mailing address: Building 32, CQUniversity, Rockhampton QLD 4702).

Effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists

Consent Form

I consent to participation in this research project (The effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists) and agree that:

1. An Information Sheet has been provided to me that I have read and fully understood.
2. Any questions I had about the project have been answered to my satisfaction by the Information Sheet and further verbal explanations.
3. I understand that my participation or non-participation in the research project will not affect my medical care.
4. I understand that I have the right to withdraw from the project at any time for any reason without penalty or prejudice.
5. I understand the pooled research findings will be included in the researcher's publication(s) on the project (The effect of concurrent strength and cycle sprint training on sprint cycling performance, muscle morphology and neuromuscular factors in veteran cyclists). Project results may be presented at conferences, and may appear in journal articles and in a PhD thesis.
6. I understand that to preserve anonymity and maintain confidentiality of participants, a research ID number will be assigned to each participant and that all data collected will be carefully stored in a secure location in a manner that keeps all personal information confidential.
7. I am aware that a Plain English statement of results will be available to participants following the analysis of all study-related results.
8. I agree that I am providing informed consent to participate in this project (Effects of Concurrent Strength and Sprint Training on Lean Mass, Strength, Power and Sprint Performance in Masters Road Cyclists).

Signature:

Date:

Name (please print):

Witness:

Witness Date:

Appendix B

12-Week Track cycling program

12-Week Mixed Methods Resistance Training Program

Track Cycling 12 Week Master-Sprint-Specific Program

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Week 1	Base Weight Training - Day 1	Track Cycling K1 92, 94, 96	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110
Week 2	Base Weight Training - Day 1	Track Cycling K1 92, 94, 96	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110
Week 3	Base Weight Training - Day 1	Track Cycling K1 94, 96, 98	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110
Week 4 UNLOAD WEEK	Base Weight Training - Day 1	Track Cycling K1 94, 96, 98 UNLOAD	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110
Week 5	Base Weight Training - Day 1	Track Cycling K1 94, 96, 98	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110
Week 6	Base Weight Training - Day 1	Track Cycling K1 96, 98, 100	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110
Week 7	Base Weight Training - Day 1	Track Cycling K1 96, 98, 100	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110

Week 8 UNLOAD WEEK	Base Weight Training - Day 1	Track Cycling K1 96, 98, 100 UNLOAD	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Monday**
Week 9	Base Weight Training - Day 1	Track Cycling K1 102, 100, 98	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110	Track Fly 100m X 3 104, 102, 100
Week 10	Base Weight Training - Day 1	Track Cycling K1 100, 98, 96	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110	Track Fly 100m X 3 102, 100, 98
Week 11	Base Weight Training - Day 1	Track Cycling K1 98, 96, 94	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110	Track Fly 100m X 3 100, 98, 96
Week 12 UNLOAD WEEK	Base Weight Training - Day 1	Track Cycling K1 96, 98, 100 UNLOAD	Base Weight Training - Day 2	Road Base Endurance Recovery 50/70% RPM 90-110	OFF	Road Base Endurance Recovery 50/70% RPM 90-110	Race Equipment (Wheels/Helmet etc…) 1 X 200m Fly Race gear: Coach selection Racing day warm up
Tuesday k-1 Sessions			**Thursday Fly Session**			**Off bike warm up:**	

Warm Up 1st set • 3 x 65 meter sprints from a standing start • 1 x 100 meter sprint from a flying start from the bottom of banking (20kph) • Rest 3-5 minutes between sprints • Change Gears for next set, rest for 10-15 minutes 2nd Set • 3 x 65 meter sprints from a standing start • 1 x 200 meter sprint from a flying start from the bottom of banking (20kph) • Rest 3-5 minutes between sprints • Change Gears for next set, rest for 10 minutes 3rd Set • 3 x 65 meter sprints from a standing start • 1 x 333 meter sprint from a flying start from the top banking • Rest 3-5 minutes between sprints Cool Down	Warm Up 1st Set • 3 x 100 meters flying seated starts (20kph) • Rest 3-5 minutes between sprints • Change Gears, Rest 10-15 minutes 2nd Set • 2 x 330 meter flying start (3 x build up laps, hitting the start line at maximum speed). Cool Down	• 15 min. rollers, last min. hard • Lateral shuffles 1 X 5 ea. • Lateral carioca 1 X 5 ea. • Leg swings 1 X 5 (6 ways). • Jump Squats 1 X 5. • 3 min. rollers, 10 sec efforts. • Lunge jumps 1 X 3 ea. • Finish with in 15 min. of event or training track session.

Notes

Rollers:

Use the 53 X 17 gear on your road bike and pedal for 30 mins with a max 10 second effort every 10 mins. So efforts @ 10, 20 and 30 mins. This will serve as an activation session (tapering week etc…) and track replacement session (weather/booking etc issues) and begin to pick up your leg speed again.

Appendix C

Raw Data

Raw Data – Study 1 – Chapter 4

Raw Data – Study 2 – Chapter 5

Raw Data – Study 3 – Chapter 6

12- Week Mixed Methods Resistance Training Program

Monday	**Hypertrophy Phase (Weeks 1-4)**				**Wednesday**	**Hypertrophy Phase (Weeks 1-4)**			
Warm Up/Pre-Activation	**wk1**	**wk2**	**wk3**	**wk4**	**Warm Up/Pre-Activation**	**wk1**	**wk2**	**wk3**	**wk4**
Stationary Bike	5 minutes @ self selected intensity	5 minutes @ self selected intensity	5 minutes @ self selected intensity	5 minutes @ self selected intensity	Stationary Bike	5 minutes @ self selected intensity	5 minutes @ self selected intensity	5 minutes @ self selected intensity	5 minutes @ self selected intensity
Plyometric - (total foot contacts = 48)					**Plyometric - (total foot contacts = 48)**				
ankle hops	2x8	2x10	2x12	2x10	ankle hops	2x8	2x10	2x12	2x10
side to side ankle hops	2x8	2x10	2x12	2x10	side to side ankle hops	2x8	2x10	2x12	2x10
standing jump & reach	2x8	2x10	2x12	2x10	standing jump & reach	2x8	2x10	2x12	2x10
Strength					Core Lifts				
Leg Press	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12	Leg Press	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12
Seated Hip Flexion	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12	Seated Hip Flexion	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12
Hypertrophy					Assistance Lifts				
Leg Curls	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4	Leg Curls	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
Leg Ext	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4	Leg Ext	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
seated Calve Raise	40% 12 x 4	50% 12 x 6	55% 12 x 4	45% 12 x 4	Calve Raise standing	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
Chest Press *	40% 12 x 4	50% 12 x 7	55% 12 x 4	45% 12 x 4	Shoulder Press	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
Prone row *	40% 12 x 4	50% 12 x 8	55% 12 x 4	45% 12 x 4	Lat Pulldown	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
Stability					Stability				
plank	2x20 secs	2x30sec	1x60	3x30sec	plank	2x20 secs	2x30sec	1x60	3x30sec
prone back extensions	2x10	2x12	2x15	3x12	prone back extensions	2x10	2x12	2x15	3x12
Recovery					Recovery				
Static Stretching	2-3 x 30 second holds all muscle groups				Static Stretching	2-3 x 30 second holds all muscle groups			
Foam Roller	thighs, ITB, Hamstring and Calves				Foam Roller	thighs, ITB, Hamstring and Calves			

Monday	Strength Phase (Weeks 4-8)				Wednesday	Strength Phase (Weeks 4-8)			
Warm Up/Pre-Activation	**wk5**	**wk6**	**wk7**	**wk8**	**Warm Up/Pre-Activation**	**wk5**	**wk6**	**wk7**	**wk8**
Stationary Bike	5 mins @ self-selected intensity				Stationary Bike	5 mins @ self-selected intensity			
Plyometric -Strength Phase (total foot contacts 50-72)					**Plyometric -Strength Phase (total foot contacts 50-72)**				
Front Box Jump	2x10	2x12	2x15	2x12	Front Box Jump	2x10	2x12	2x15	2x12
jump from box	2x10	2x12	2x15	2x12	depth jump	2x10	2x12	2x15	2x12
lateral box jump	1x5 ea	2x6ea	2x8ea	2x6ea	lateral box jump	1x5 ea	2x6ea	2x8ea	2x6ea
Foot contacts	50	60	76	60	Foot contacts	50	60	76	60
Ballistic Power lift					**Ballistic Power lift**				
single leg press throw	20% 2x5	30% 2x5	40% 2x5	30% 3x5	single leg press throw	20% 2x5	30% 2x5	40% 2x5	30% 3x7
Strength					**Strength**				
SL Leg Press	70% 3 x 8	75% 3 x 8	80% 3x6	75% 3 x 8	SL Leg Press	70% 3 x 8	75% 3 x 8	80% 3x6	75% 3 x 8
Seated Hip Flexion	70% 3 x 8	75% 3 x 8	80% 3x6	75% 3 x 8	Seated Hip Flexion	70% 3 x 8	75% 3 x 8	80% 3x6	75% 3 x 8
Neuro-conversion									
Spin bike sprints	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s	Spin bike sprints	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s
Hypertrophy					**Hypertrophy**				
Leg Extensions	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Leg Extension	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Leg Ext	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Leg Curls	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Calve Raise	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Calve Raise standing	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Chest Press	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Chest Press	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Prone row	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Prone Row	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Stability					**Stability**				

Monday	**Strength Phase (Weeks 4-8)**				**Wednesday**	**Strength Phase (Weeks 4-8)**			
Advanced Curl up	2x10	2x12	2x15	3x12	Modified Curl up	2x10	2x12	2x15	3x12
bird dog	2x10	2x12	2x15	3x12	bird dog	2x10	2x12	2x15	3x12
Recovery					**Recovery**				
Static Stretching	2-3 x 30 second holds all muscle groups				Static Stretching	2-3 x 30 second holds all muscle groups			
Foam Roller	thighs, ITB, Hamstring and Calves				Foam Roller	thighs, ITB, Hamstring and Calves			

Monday	**Power Phase (Weeks 8-12)**				**Wednesday**	**Power Phase (Weeks 8-12)**			
Warm Up/Pre-Activation	**wk9**	**wk10**	**wk11**	**wk12**	**Warm Up/Pre-Activation**	**wk9**	**wk10**	**wk11**	**wk12**
Stationary Bike	5 mins @ self-selected intensity				Stationary Bike	5 mins @ self-selected intensity			
Plyometric (foot Contacts 60-120)					Plyometric (foot Contacts 60-120)				
alternating step push offs	1x10 ea	1x15 ea.	1x20 ea	2x15 ea	alternating step push offs	1x10 ea	1x15 ea.	1x20 ea	2x15 ea
single leg box push offs	1x10 ea	1x15 ea.	1x20 ea	2x15 ea	single leg box push offs	1x10 ea	1x15 ea.	1x20 ea	2x15 ea
squat depth jumps	2x10	2x15	2x20	2x15	squat depth jumps	2x10	2x15	2x20	2x15
ballistic Power Lifts					ballistic Power Lifts				
single leg press throw	45% 3x5	50% 3x5	60% 3x5	55% 3x5	single leg press throw	45% 3x5	50 3x5%	60% 3x5	55% 3x5
Strength					Strength				
SL Leg Press	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3	SL Leg Press	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3
Seated Hip Flexion	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3	Seated Hip Flexion	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3
Neuro-conversion					Neuro-conversion				
Spin bike sprints	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s	Spin bike sprints	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s	3 x 10s:60s
Hypertrophy					Hypertrophy				
Leg Cruls	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Leg Curl	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Leg Ext	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Leg Ext	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
seated Calve Raise	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Calve Raise standing	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Chest Press	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Chest Press	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Prone row	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Prone row	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Stability					Stability				
Advanced Curl up	2x10	2x12	2x15	3x12	Advanced Curl up	2x10	2x12	2x15	3x12

Monday	**Power Phase (Weeks 8-12)**				**Wednesday**	**Power Phase (Weeks 8-12)**			
back ext bench	2x10	2x12	2x15	3x12	back ext bench	2x10	2x12	2x15	3x12
Recovery					Recovery				
Static Stretching	2-3 x 30 second holds all muscle groups				Static Stretching	2-3 x 30 second holds all muscle groups			
Foam Roller	thighs, ITB, Hamstring and Calves				Foam Roller	thighs, ITB, Hamstring and Calves			

Raw Data – Study 3 – Chapter 4

Reliability of Squat Jump and Countermovement Jump Performance in Masters Athletes

Squat Jump Raw Data

	SJ PP (watts)		**SJ RFD (N/s)**		**SJ PF (N)**		**SJ HT (cm)**		**SJ PP/BM (W.kg)**		**SJ PF/BM (N.kg)**	
	Test 1	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**
Subject 1												
trial 1	1,424.5	1744.3	13,217.3	10,787.0	1,965.6	2,080.9	0.17	0.13	15.8	19.3	21.8	23.1
trial 2	1,345.5	1549.7	12,622.6	11,102.3	2,020.7	2,060.7	0.12	0.14	14.9	17.2	22.4	22.9
trial 3	1,404.9	1549.7	13,377.2	11,102.3	2,014.2	2,091.4	0.13	0.17	15.6	17.2	22.3	23.2
Subject 2	**1,391.6**	**1,614.5**	**13,072.3**	**10,997.2**	**2,000.2**	**2,077.7**	**0.14**	**0.15**	**15.4**	**17.9**	**22.2**	**23.0**
trial 1	2,211.6	2,511.3	16,258.5	13,022.9	2,253.9	2,293.3	0.27	0.19	24.5	27.9	25.0	25.4
trial 2	2,249.1	2,668.8	14,413.1	12,198.8	2,209.3	2,309.6	0.27	0.20	24.9	29.6	24.5	25.6
trial 3	2,345.34	2,817.5	18,135.2	18,387.9	2,223.9	2,413.5	0.29	0.20	26.0	31.3	24.7	26.8
Subject 3	**2,268.7**	**2,665.9**	**16,268.9**	**14,536.5**	**2,229.1**	**2,338.8**	**0.28**	**0.19**	**25.2**	**29.6**	**24.7**	**25.9**
trial 1	1,284.8	896.5	8,694.1	4,219.3	1,923.9	1,841.2	0.12	0.08	14.2	9.9	21.3	20.4
trial 2	1,232.1	1,078.0	5,476.3	4,532.6	1,795.9	1,792.6	0.12	0.11	13.6	11.9	19.9	19.9
trial 3	1,263.7	990.4	7,297.6	4,934.2	1,844.1	1,828.0	0.12	0.11	14.0	11.0	20.4	20.3
Subject 4	**1,260.2**	**988.3**	**7,156.0**	**4,562.0**	**1,854.6**	**1,820.6**	**0.12**	**0.10**	**14.0**	**10.9**	**20.6**	**20.2**
trial 1	1,677.1	1,409.5	13,753.1	15,009.9	1,630.8	1,610.01	0.21	0.20	18.63	15.6	18.1	17.8
trial 2	1,779.0	1,588.5	20,540.8	17,681.6	1,841.0	1,726.6	0.20	0.20	19.77	17.6	20.4	19.1

	SJ PP (watts)		SJ RFD (N/s)		SJ PF (N)		SJ HT (cm)		SJ PP/BM (W.kg)		SJ PF/BM (N.kg)	
trial 3	1,719.9	1,875.4	18,877.00	19,486.2	1,740.3	1,883.5	0.21	0.20	19.1	20.8	19.3	20.9
Subject 5	**1,725.3**	**1,624.5**	**17,723.63**	**17,392.5**	**1,737.3**	**1,740.0**	**0.21**	**0.20**	**19.1**	**18.0**	**19.3**	**19.3**
trial 1	2,373.3	2,396.1	12,162.50	11,505.5	1,844.9	2,147.2	0.19	0.21	26.3	26.6	20.5	23.8
trial 2	2,416.2	2,395.9	12,179.50	10,832.1	1,867.2	2,091.4	0.21	0.22	26.8	26.6	20.7	23.2
trial 3	2,402.1	2,328.9	8,599.68	11,016.6	1,863.0	2,119.3	0.24	0.20	26.6	25.8	20.7	23.5
Subject 6	**2,397.2**	**2,373.6**	**10,980.56**	**11,118.0**	**1,858.4**	**2,119.3**	**0.21**	**0.21**	**26.6**	**26.3**	**20.6**	**23.5**
trial 1	1,037.8	1,183.2	6,248.93	4,703.6	1,652.6	1,376.5	0.17	0.19	11.5	13.1	15.2	18.3
trial 2	1,146.3	1,210.8	4,260.03	5,753.9	1,572.6	1,422.5	0.19	0.21	12.7	13.4	15.8	17.4
trial 3	993.2	1,211.5	5,853.93	5,105.9	1,546.7	1,371.1	0.17	0.21	11.0	13.4	15.2	17.1
Subject 7	**1,059.1**	**1,201.9**	**5,454.30**	**5,187.8**	**1,390.0**	**1,590.6**	**0.18**	**0.21**	**11.7**	**13.3**	**15.4**	**17.6**
trial 1	2,021.6	2,604.8	9,298.08	8,953.5	1,904.0	2,070.2	0.23	0.29	22.4	28.9	21.1	23.0
trial 2	2,250.0	2,623.0	17,514.20	10,828.1	2,191.9	2,116.8	0.22	0.28	25.0	29.1	24.3	23.5
trial 3	2,297.6	2,502.7	1,300.40	9,990.3	2,079.6	2,070.8	0.24	0.26	25.5	27.8	23.1	23.0
Subject 8	**2,189.7**	**2,576.8**	**9,370.89**	**9,924.0**	**2,058.5**	**2,085.9**	**0.23**	**0.28**	**24.3**	**28.6**	**22.8**	**23.1**
trial 1	1,782.0	2,059.1	10,163.90	8,192.8	1,715.2	1,696.3	0.24	0.26	19.8	22.8	19.0	18.8
trial 2	1,778.7	1,957.7	9,222.05	7,582.4	1,644.5	1,674.8	0.25	0.25	19.7	21.7	18.2	18.6
trial 3	1,895.5	2,031.5	6,438.00	6,897.7	1,569.7	1,656.6	0.27	0.24	21.0	22.5	17.4	18.4
Subject 9	**1,818.7**	**2,016.1**	**8,607.98**	**7,557.7**	**1,643.1**	**1,675.9**	**0.25**	**0.25**	**20.2**	**22.4**	**18.2**	**18.6**
trial 1	1,397.4	1,418.6	7,476.53	8,180.2	1,591.4	1,669.8	0.19	0.19	15.5	15.7	17.6	18.5
trial 2	1,437.8	1,514.3	6,413.91	8,370.4	1,493.6	1,690.1	0.21	0.18	15.9	16.8	16.6	18.7
trial 3	1,325.0	1,576.4	5,683.23	6,341.6	1,481.7	1,649.4	0.21	0.18	14.7	17.5	16.4	18.3

	SJ PP (watts)		SJ RFD (N/s)		SJ PF (N)		SJ HT (cm)		SJ PP/BM (W.kg)		SJ PF/BM (N.kg)	
Subject 10	**1,386.7**	**1,503.1**	**6,524.5**	**7,630.7**	**1,522.3**	**1,669.8**	**0.20**	**0.18**	**15.4**	**16.7**	**16.9**	**18.5**
trial 1	1,783.0	1731.9	5,000.7	5,341.3	1,785.4	1,752.9	0.19	0.22	19.8	19.2	19.8	19.4
trial 2	1,658.6	1695.0	6,715.6	6,342.4	1,782.6	1,770.7	0.21	0.23	18.4	18.8	19.8	19.6
trial 3	1,602.1	1710.3	5,749.5	TPKB	1,674.3	1,770.7	0.22	0.23	17.8	19.0	18.6	19.6
	1,681.2	**1,712.4**	**5,821.9**	**5,841.8**	**1,747.4**	**1,764.8**	**0.21**	**0.23**	**18.6**	**19.0**	**19.4**	**19.6**

Countermovement Jump Raw Data

	CMJ PP (Watts)		CMJ PF (N)		CMJ RFD (N/s)		CMJ HT (cm)		CMJ PP/BM (N.kg)		CMJ PF/BM (N.kg)	
	Test 1	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**
Subject 1	1,645.3	1,644.2	1,943.9	2,331.1	14,000.0	14,295.7	0.15	0.15	18.2	18.2	21.6	25.9
trial 1	1,569.9	1,711.74	2,081.1	2,132.7	14,694.1	11,387.0	0.18	0.20	17.4	19.0	23.1	23.7
trial 2	1,739.1	1,711.74	1,973.9	2,298.7	14,666.7	11,387.0	0.18	0.20	19.3	19.0	21.9	25.5
trial 3	**1,651.4**	**1,689.24**	**1,999.6**	**2,254.1**	**14,453.6**	**12,356.5**	**0.17**	**0.19**	**18.3**	**18.7**	**22.2**	**25.0**
Subject 2	1,625.4	1,819.20	1,966.0	2,103.3	11,824.6	16,511.0	0.20	0.21	18.0	20.2	21.8	23.3
trial 1	1,808.1	1,664.36	1,953.4	1,925.1	14,504.5	12,393.7	0.23	0.23	20.0	18.4	21.7	21.3
trial 2	1,569.5	1,570.11	1,830.3	1,843.5	11,000.0	14,690.8	0.21	0.21	17.4	17.4	20.3	20.4
trial 3	**1,667.6**	**1,684.56**	**1,916.6**	**1,957.3**	**12,443.0**	**14,531.8**	**0.21**	**0.22**	**18.5**	**18.7**	**21.3**	**21.7**
Subject 3	1,183.3	1,190.00	1,808.8	1,203.2	6,272.7	4,700.7	0.13	0.10	13.1	13.2	20.1	13.3
trial 1	1,049.9	1,073.99	1,579.8	714.6	5,148.3	4,679.3	0.14	0.12	11.6	11.9	17.5	7.9

	CMJ PP (Watts)		**CMJ PF (N)**		**CMJ RFD (N/s)**		**CMJ HT (cm)**		**CMJ PP/BM (N.kg)**		**CMJ PF/BM (N.kg)**	
trial 2	988.4	1,137.6	1,613.3	714.5	4,934.4	4,331.1	0.33	0.13	10.9	12.6	17.9	7.9
trial 3	**1,073.9**	**1,133.8**	**1,667.3**	**877.4**	**5,451.8**	**4,570.4**	**0.20**	**0.12**	**11.9**	**12.6**	**18.5**	**9.7**
Subject 4	1,811.8	1,611.6	2,098.2	1,906.1	18,268.6	13,346.9	0.22	0.22	20.1	17.9	23.3	21.1
trial 1	1,685.4	1,539.9	1,993.0	1,909.9	17,171.0	13,586.2	0.23	0.24	18.73	17.1	22.1	21.2
trial 2	1,706.7	1,685.0	2,125.2	1,995.3	20,704.6	16,857.2	0.23	0.24	18.96	18.7	23.6	22.1
trial 3	**1,734.7**	**1,612.2**	**2,072.1**	**1,937.1**	**18,714.7**	**14,596.7**	**0.23**	**0.23**	**19.27**	**17.9**	**23.0**	**21.5**
Subject 5	2,335.1	2,016.3	2,068.1	2,495.1	11,851.8	7,723.3	0.21	0.24	25.95	22.4	22.9	27.7
trial 1	2,257.2	2,143.4	2,108.0	2,380.6	11,679.4	10,274.0	0.22	0.24	25.08	23.8	23.4	26.4
trial 2	2,344.9	2,048.1	2,036.8	2,511.4	8,661.8	10,337.1	0.21	0.25	26.05	22.7	22.6	27.9
trial 3	**2,312.4**	**2,069.3**	**2,071.0**	**2,462.4**	**10,731.0**	**9,444.8**	**0.21**	**0.25**	**25.69**	**22.9**	**23.0**	**27.3**
Subject 6	1,040.9	1,264.3	1,508.3	1,417.0	4,533.4	5,838.7	0.20	0.21	11.57	14.0	16.7	15.7
trial 1	1,081.0	1,268.9	1,477.6	1,370.4	4,371.5	1,403.3	0.19	0.22	12.01	14.1	16.4	15.2
trial 2	1,201.9	1,238.5	1,522.1	1,349.9	4,695.4	7,149.1	0.24	0.22	13.36	13.7	16.9	15.0
trial 3	**1,107.9**	**1,257.2**	**1,502.7**	**1,379.1**	**4,533.4**	**4,797.0**	**0.21**	**0.22**	**12.31**	**13.9**	**16.7**	**15.3**
Subject 7	1,797.8	1,930.8	1,964.9	1,869.1	9,773.0	8,589.6	0.24	0.30	19.98	21.4	21.8	20.7
trial 1	1,874.8	2,029.3	2,006.5	1,790.7	11,077.6	8,367.4	0.25	0.32	20.83	22.5	22.2	19.9
trial 2	1,747.7	1,787.0	1,847.3	1,789.3	10,000.0	8,476.8	0.26	0.28	19.42	19.8	20.5	19.8
trial 3	**1,806.8**	**1,915.7**	**1,939.5**	**1,816.4**	**10,283.5**	**8,477.9**	**0.25**	**0.30**	**20.08**	**21.2**	**21.5**	**20.1**
Subject 8	1,650.3	1,562.5	1,408.6	1,445.2	7,118.8	5,835.2	0.28	0.28	18.34	17.3	15.6	16.0
trial 1	1,716.4	1,494.0	1,522.3	1,381.3	8,179.2	7,348.1	0.29	0.29	19.07	16.6	16.9	15.3
trial 2	1,584.1	1,483.1	1,458.9	1,411.3	6,058.4	13,895.2	0.28	0.28	17.60	16.4	16.2	15.6

	CMJ PP (Watts)		**CMJ PF (N)**		**CMJ RFD (N/s)**		**CMJ HT (cm)**		**CMJ PP/BM (N.kg)**		**CMJ PF/BM (N.kg)**	
trial 3	**1,650.3**	**1,513.2**	**1,463.2**	**1,412.6**	**7,118.8**	**9,026.2**	**0.28**	**0.28**	**18.3**	**16.8**	**16.2**	**15.7**
Subject 9	1,427.1	1,732.0	1,713.3	1,732.0	9,432.2	13,113.8	0.18	0.16	15.8	19.2	19.0	19.2
trial 1	1,531.1	1,441.5	1,729.2	1,941.5	6,452.9	11,821.0	0.20	0.15	17.0	16.0	19.2	21.5
trial 2	1,394.0	1,394.0	1,685.6	1,917.9	4,625.9	4,625.9	0.20	0.20	15.4	15.4	18.7	21.3
trial 3	**1,450.7**	**1,522.5**	**1,709.4**	**1,863.8**	**6,837.0**	**9,853.5**	**0.20**	**0.17**	**16.1**	**16.9**	**18.9**	**20.7**
Subject 10	1,505.9	1689.2	1,651.1	1,757.3	4,798.7	5000.2	0.23	0.27	16.7	18.7	18.3	19.5
trial 1	1,596.0	1654.7	1,724.5	1,733.8	4,435.0	4792.4	0.24	0.27	17.7	18.3	19.1	19.2
trial 2	1,547.0	1653.6	1,693.9	1,713.9	4,558.6	5283.8	0.24	0.25	17.1	18.3	18.8	19.0
trial 3	**1,549.6**	**1,665.9**	**1,689.8**	**1,735.0**	**4,597.4**	**5,025.5**	**0.24**	**0.26**	**17.2**	**18.5**	**18.7**	**19.2**

Raw Data – Study 4 – Chapter 5

Effect of Concurrent Resistance and Sprint Training on Body Composition and Cardiometabolic Health Indicators in Masters Cyclists

Resistance & Track Cycling Group	**Age (yrs)**	**Stature (m)**	**Mass (kg)**		***V02 Peak (ml..kg.min)***		**TC (mmol.l)**		**TG (mmol.l)**		**Glucose (mmol.l)**		**SBP (mm.hg)**		**DBP (mm.hg)**	
			pre	**post**	***pre***	***post***	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	72.0	1.78	76.0	78.0	34.7	41.5	3.1	3.0	1.2	0.8	4.5	4.7	116	113	73	71
Subject 2	46.0	1.80	85.8	82.7	40.0	47.2	4.7	2.5	1.0	0.8	5.2	5.4	110	117	70	72
Subject 3	55.0	1.81	89.0	90.4	39.5	34.0	4.2	4.2	1.3	1.5	5.3	6.4	128	124	84	87
Subject 4	41.0	1.63	71.0	70.1	47.0	47.5	5.2	5.4	0.8	1.1	5.0	3.6	129	117	80	72
Subject 5	53.0	1.89	82.4	84.0	46.9	38.6	5.8	5.4	0.8	0.8	4.8	3.0	119	117	76	72
Subject 6	58.0	1.70	84.0	87.3	37.0	34.8	2.5	3.6	0.9	0.8	5.6	5.9	120	111	76	74
Subject 7	45.0	1.82	80.9	82.0	65.0	61.1	3.9	3.7	0.8	0.7	5.0	5.3	119.0	113	79	79
Subject 8	55.0	1.81	85.2	90.0	50.1	49.3	3.3	2.7	0.8	0.8	4.9	5.9	124	132	80	84
Subject 9	60.0	1.83	90.1	92.0	54.0	50.7	4.8	4.8	0.7	0.8	5.2	6.5	122	120	88	78
Subject 10	50.0			74.0	52.9	51.7	4.1	4.0	0.8	0.8	5.6	4.0	129	125	80	83
mean	*53.5*	*1.79*	*82.7*	*83.6*	*46.71*	*45.64*	*4.2*	*3.9*	*0.92*	*0.90*	*5.15*	*5.09*	*121.7*	*119.1*	*78*	*77*
SD	*9.3*	*0.08*	*6.1*	*6.9*	*9.27*	*8.43*	*1.0*	*1.1*	*0.22*	*0.26*	*0.30*	*1.21*	*5.9*	*6.5*	*5.5*	*6.5*

sprint only Group	**Age (yrs)**	**Stature (m)**	**Mass (kg)**		***V02 Peak (ml.kg.min)***		**TC (mmol.l)**		**TG (mmol.l)**		**Glucose (mmol.l)**		**SBP (mm.hg)**		**DBP (mm.hg)**	
			Pre	**Post**	***pre***	***post***	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	Pre	Post	Pre	**Post**
Subject 1	49.0	1.80	79.3	79.0	38.0	38.9	4.4	2.5	1.8	3.2	5.3	5.0	*127*	*123*	*80*	77
Subject 2	55.0	1.82	76.3	77.0	38.2	48.1	5.3	5.5	1.0	1.9	6.8	5.4	*117*	*114*	*79*	74
Subject 3	41.0	1.80	77.4	78.0	56.2	51.5	4.4	2.5	1.4	1.9	4.7	5.5	*127*	*126*	*76*	80
Subject 4	48.0	1.65	73.0	72.5	66.6	63.4	4.6	4.5	0.8	0.8	4.4	4.8	*145*	*139*	*80*	81
Subject 5	53.0	1.84	90.8	88.0	55.9	50.0	4.6	5.1	0.8	1.1	5.4	2.5	*121*	*114*	*80*	73
Subject 6	47.0	1.71	73.0	74.3	61.1	56.3	5.7	5.5	0.8	1.4	4.8	4.3	*131*	*113*	*78*	68
Subject 7	53.0	1.68	79.9	80.8	46.4	42.6	3.3	3.8	0.8	0.8	5.4	4.9	*133*	*120*	*89*	89
mean	*49.4*	*1.76*	*78.5*	*78.5*	*51.7*	*50.1*	*4.6*	*4.2*	*1.0*	*1.6*	*5.3*	*4.6*	*129*	*121*	*80*	*77*
SD	*4.7*	*0.3*	*6.0*	*5.0*	*11.1*	*8.2*	*0.7*	*1.2*	*0.4*	*0.8*	*0.8*	*1.0*	*9.0*	*9.3*	*4.1*	*6.9*

Control Group	**Age (yrs)**	**Stature (m)**	**Mass (kg)**		***V02 Peak (ml.kg.min)***		**TC (mmol.l)**		**TG (mmol.l)**		**Glucose (mmol.l)**		***SBP (mm.hg)***		***DBP (mm.hg)***	
			pre	**post**	***pre***	***post***	**pre**	**post**	**pre**	**post**	**pre**	**post**	***pre***	***post***	***pre***	***post***
Subject 1	51.0	1.72	86.7	88.0	44.0	40.0	6.0	5.9	1.5	1.2	4.8	4.4	132	129	91	84
Subject 2	55.0	1.68	75.0	76.3	19.5	37.0	5.2	2.5	6.8	3.5	5.2	6.5	138	144	86	94
Subject 3	53.0	1.64	75.0	74.4	44.4	40.2	8.0	7.2	1.9	2.6	4.8	4.6	157	140	96	94
Subject 4	57.0	1.79	87.0	88.0	31.2	40.0	2.8	3.0	1.1	0.9	4.2	5.2	139	139	89	90
Subject 5	48.0	1.87	90.0	88.5	36.8	50.0	4.53	4.5	2.1	1.1	5.5	4.1	133	118	90	80
Subject 6	76.0	1.61	77.0	77.0	29.3	30.9	4.1	5.0	0.8	0.8	5.6	5.3	146	188	82	85
Subject 7	63.0	1.77	81.1	77.7	38.3	38.0	4.0	3.4	1.1	0.9	6.4	4.1	130	134	80	85
Subject 8	57.0	1.67	69.6	69.0	50.9	45.8	4.7	2.7	0.8	1.9	4.6	5.5	143	157	100	98
Subject 9	62.0	1.82	91.2	91.0	40.0	30.3	4.3	4.2	0.9	0.9	5.1	6.6	116	129	78	84
Subject 10	47.0	1.88	103.	103.0	41.3	34.9	5.9	6.2	0.9	2.0	5.0	5.4	120	134	80	84
mean	*56.0*	*1.75*	*83.5*	*83.30*	*37.5*	*38.5*	*5.0*	*4.5*	*1.8*	*1.6*	*5.1*	*5.2*	*135*	*141*	*87*	*88*
SD	*8.5*	*0.10*	*9.9*	*10.1*	*8.9*	*6.4*	*1.41*	*1.5*	*1.8*	*0.6*	*0.6*	*0.6*	*12.2*	*19.3*	*7.2*	*5.9*

Raw Data – Study 5 – Chapter 6

Effect of concurrent strength and sprint training on lean mass, strength, power and sprint performance in masters road cyclists.

CT Group	**Age (yrs)**	**Stature (m)**	**Mass (kg)**		**WBLM (g)**		**LLLM (g)**		**CMJ (cm)**		**QPT (Nm·kg^{-1})**		**HPT (Nm·kg^{-1})**		**PP10 (W.kg)**		**TW (J.kg)**		**MAP (watts)**		**TT (sec)**	
			pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	72.0	1.78	76.0	78.0	58413.4	59552.9	34435.0	42793.3	0.28	0.26	221.0	233.6	70.8	83.1	528.0	565.0	13493.5	14105.0	275.0	300.0	13.9	13.2
Subject 2	55.0	1.81	89.0	90.4	61787.3	63591.0	26444.9	32677.4	0.23	0.26	192.00	216.7	87.2	103.5	1128.0	1113.0	22978.5	23563.7	300.0	275.0	16.9	14.9
Subject 3	41.0	1.63	71.0	70.1	53971.0	53674.2	31046.9	37413.4	0.27	0.29	231.0	257.3	69.7	97.5	855.0	865.0	17768.6	18472.4	300.0	300.0	18.2	15.3
Subject 4	53.0	1.89	82.4	84.0	61498.0	63194.9	28033.5	34879.5	0.28	0.26	297.0	308.3	101.1	123.9	966.0	982.0	20615.1	21239.6	300.0	300.0	16.2	14.6
Subject 5	58.0	1.70	84.0	87.3	57222.4	60467.1	29428.3	36110.5	0.21	0.21	154.0	231.6	62.0	81.5	889.0	815.0	19048.4	19448.0	300.0	275.0	17.5	17.4
Subject 6	45.0	1.82	80.9	82.0	67476.6	67566.2	30135.5	36661.4	0.25	0.28	234.3	236.0	120.3	107.1	1017.0	1007.0	23705.0	21953.5	450.0	425.0	13.6	13.3
Subject 7	55.0	1.81	85.2	90.0	68542.2	70290.0	34139.5	42171.2	0.25	0.26	237.0	273.0	79.5	82.2	1118.0	1118.0	22000.0	23923.1	375.0	400.0	18.1	15.6
Subject 8	60.0	1.83	90.1	92.0	69840.2	69986.7	29587.1	36512.4	0.16	0.15	241.0	286.8	99.9	117.2	932.0	957.0	20293.0	20893.7	400.0	400.0	13.4	13.3
Subject 9	50.0	1.64	73.0	74.0	58302.8	59613.0	34811.4	41898.6	0.28	0.30	233.2	215.3	68.9	62.7	884.0	1010.0	21046.5	22821.7	375.0	375.0	16.1	15.1
mean	54.3	1.77	81.3	83.1	61894.8	63104.0	30895.7	37901.9	0.25	0.25	226.7	251.0	84.3	95.4	924.1	936.8	20105.4	20713.4	341.6	338.8	16.0	14.7
SD	8.4	0.9	6.3	7.2	5252.3	5162.2	2805.7	3357.8	0.04	0.0	36.3	30.7	18.2	18.5	168.0	161.5	2911.2	2887.0	56.5	56.6	1.8	1.2

ST Group	Age (yrs)	Stature (m)	Mass (kg)		WBLM (g)		LLLM (g)		CMJ (cm)		QPT ($Nm \cdot kg^{-1}$)		HPT ($Nm \cdot kg^{-1}$)		PP10 (W.kg)		TW (J.kg)		MAP (watts)		TT (sec)	
			pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	49.0	1.80	79.3	79.0	61389.1	61686.5	17079.3	17948.7	0.52	0.26	307.0	280.4	105.5	107.2	1076.0	1026.0	23162.5	22080.2	325.0	300.0	16.1	14.4
Subject 2	55.0	1.82	76.3	77.0	62186.9	58385.2	15490.1	15482.7	0.18	0.22	236.4	233.2	66.9	71.4	789.0	959.0	17648.6	18086.0	325.0	325.0	16.0	15.1
Subject 3	41.0	1.80	77.4	78.0	59387.9	58406.6	16159.5	17863.2	0.21	0.26	225.7	204.7	89.9	93.0	1033.0	1039.0	21770.8	22275.2	350.0	375.0	13.5	13.5
Subject 4	48.0	1.65	73.0	72.5	55005.6	56337.7	15678.4	16105.1	0.20	0.20	199.7	186.2	83.4	85.6	788.0	759.0	15999.2	17519.8	400.0	425.0	14.0	14.5
Subject 5	53.0	1.84	90.8	88.0	69773.6	70663.2	19871.9	19928.9	0.25	0.21	252.7	226.7	71.8	90.3	1043.0	1045.0	23525.1	23196.5	425.0	450.0	14.4	13.9
Subject 6	47.0	1.71	73.0	74.3	58123.7	59437.5	17091.5	17447.7	0.21	0.21	277.6	260.0	96.4	105.6	832.0	935.0	20175.1	19913.5	375.0	400.0	15.2	14.5
Subject 7	53.0	1.68	79.9	80.8	64027.6	66320.1	17787.6	18511.3	0.19	0.23	235.5	223.6	60.7	80.5	871.0	881.0	18603.5	21237.1	325.0	375.0	13.5	13.2
mean	49.4	1.76	78.5	78.5	61413.4	61605.2	17022.6	17612.5	0.25	0.23	247.8	230.6	82.0	90.5	918.8	949.1	20126.4	20615.4	360.7	378.5	14.7	14.2
SD	4.4	0.7	5.6	4.6	4363.9	4740.8	1394.4	1372.4	0.11	0.02	32.7	29.4	15.1	11.9	117.6	95.8	2644.8	2015.0	37.4	48.9	1.0	0.6

CG Group	Age (yrs)	Stature (m)	Mass (kg)		WBLM (g)		LLLM (g)		CMJ (cm)		QPT (Nm·kg^{-1})		HPT (Nm·kg^{-1})		PP10 (W.kg)		TW (J.kg)		MAP (watts)		TT (sec	
			pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	51.0	1.72	86.7	88.0	66109.4	64465.1	17276.2	17448.7	0.25	0.20	260.0	269.0	102.8	94.7	1005.0	938.0	21387.0	19609.4	375.0	350.0	13.0	13.1
Subject 2	55.0	1.68	75.0	76.3	56327.6	54926.7	14141.0	14026.1	0.18	0.20	175.3	157.1	73.3	85.0	816.0	844.0	17182.9	16947.2	250.0	225.0	15.5	16.6
Subject 3	53.0	1.64	75.0	74.4	57911.7	59975.8	15286.3	16652.3	0.34	0.36	256.5	261.0	69.3	76.0	919.0	935.0	19713.6	19355.1	275.0	250.0	14.7	14.7
Subject 4	57.0	1.79	87.0	88.0	67687.8	69963.6	18030.0	18506.2	0.14	0.14	119.5	231.0	69.2	79.6	725.0	580.0	17603.0	16184.1	275.0	300.0	15.2	15.9
Subject 5	48.0	1.87	90.0	88.5	65356.8	64389.9	17499.7	17517.0	0.18	0.21	297.2	316.9	104.6	122.2	1011.0	943.0	21108.4	21526.5	325.0	350.0	15.9	16.4
Subject 6	76.0	1.61	77.0	77.0	56499.9	55453.3	14957.4	14560.8	0.17	0.18	196.2	169.2	96.8	59.3	697.0	730.0	15095.5	14084.7	225.0	225.0	16.0	16.5
Subject 7	63.0	1.77	81.1	77.7	57540.8	56837.7	15135.6	15235.9	0.20	0.25	207.5	148.8	86.7	85.9	894.0	832.0	17649.3	16791.4	300.0	300.0	15.8	16.8
Subject 8	57.0	1.67	69.6	69.0	51736.2	52154.1	12851.1	12821.6	0.21	0.21	129.0	111.8	54.6	63.0	768.0	702.0	16379.0	15448.9	325.0	325.0	16.5	17.1
Subject 9	62.0	1.82	91.2	91.0	72031.5	67817.0	18886.9	17446.5	0.34	0.15	256.5	123.7	69.3	30.9	879.0	593.0	20185.9	14562.3	350.0	250.0	16.2	16.1
mean	58.0	1.73	81.4	81.1	61244.6	60664.8	16007.3	16023.9	0.22	0.21	210.8	198.7	80.7	77.4	857.1	788.5	18478.2	17290.6	300.0	284.3	15.4	15.9
SD	7.8	0.8	7.2	7.3	6327.8	5902.7	1887.0	1821.0	0.07	0.06	58.2	68.4	16.6	23.9	107.4	135.5	2076.3	2476.4	45.6	49.9	1.0	1.2