The University of Rome "Foro Italico"
The German Sport University, Cologne
The University of Southern Denmark, Odense
The Norwegian School of Sport Sciences, Oslo
The University of Vienna

European Master in Health and Physical Activity
(Laurea Magistrale Internazionale in Attività Fisica e Salute)
LM 67- I

Effects of eccentric cycling and endurance training versus low cadence cycling and endurance training on muscle strength and cycling performance in trained individuals

Hedda Øyeflaten Eidsheim___
Candidate

Bent R. Rønnestad_____
Supervisor

Gøran Paulsen______________
Co - Supervisor

Academic Year 2014-2016

Abstract

Background: Recent studies have shown a positive effect of concurrent strength and endurance training on performance in cycling. Still, few studies have investigated the effect of eccentric cycling (ECC) and low cadence cycling (LCC) on muscle strength and determinants of cycling performance.

Aim: Compare the effect of concurrent ECC and endurance training with concurrent LCC and endurance training on strength development, muscle thickness, and cycling performance in trained individuals.

Method: 23 trained men participated in a 10-week supervised training program. One group (mean age: 36.3 years, SD: 13.4) were randomly assigned ECC and aerobic intervals (n=12), while the other group (mean age: 29.4 years, SD: 10.2) were allocated to LCC and aerobic intervals (n=11). Outcome measures were knee extension peak torque (Nm), muscle thickness (cm), maximum oxygen consumption (VO_{2max}), maximum aerobic power output (W_{max}), lactate threshold (LT), cycling economy and performance during a 20 min all-out.

Results: Significant improvements were seen in both groups for VO_{2max} (mL/min/kg), W_{max}, and LT expressed as VO_2 and power output. The LCC-group increased mean power output during the 20 min all-out more than the ECC-group, while the ECC-group demonstrated larger increases for peak torque in eccentric knee extension than the LCC-group. The ECC-group had a significant increase in m. quadriceps femoris muscle thickness and a significant decline in peak torque in concentric knee extension at 60°/second. No improvements were seen in either group for percentage of VO_{2max} at the LT or cycling economy.

Conclusion: ECC does not seem to give any positive effects on cycling performance or determinants of cycling performance compared with LCC. However, ECC seems to be more effective in improving muscle strength than LCC. The strength improvements seem to be contraction specific and are related to increased muscle thickness.

Preface

This thesis is written based on data collected through a project conducted at the University of Lillehammer (HiL). In leading the project, I have organized the testing and intervention, communicated with all participants, guided seven undergraduate students in conducting testing and trainings, as well as plotted and analyzed data. The thesis was written as part of a master degree in health and physical activity; however, due to the nature of the project, the main topic is cycling performance. As my personal educational background is within health and physical activity, the topic is also presented and discussed in a health perspective with focus on rehabilitation.

The project and my thesis would not have been possible without the contribution of others. Firstly, I want to thank the participants of the project for showing up and working hard in the training sessions and giving their all during testing. Secondly, I want to thank the bachelor students at HiL for spending countless hours in the labs and gym. I also thank my supervisors Bent R. Rønnestad and Gøran Paulsen for their guidance, and Thomas Johansen for helpful inputs. Finally, I want to thank Magnus for his love and support.

Abbreviations

BF	Breathing frequency
BMD	Bone mineral density
CSA	Cross sectional area
DOMS	Delayed-onset muscle soreness
ECC	Eccentric cycling
HR	Heart rate
HR_{max}	Maximum heart rate
$[La^-]_b$	Blood lactate concentration
LCC	Low cadence cycling
LT	Lactate threshold
Mmol/L	Millimole per liter
Nm	Newton Meter
OBLA	Onset of blood lactate accumulation
RER	Respiratory exchange ratio
RM	Repetition maximum
RPE	Rate of perceived exertion
RPM	Revolutions per minute
VAS	Visual analog scale
VE	Ventilation
VO_2	Oxygen consumption
VO_{2max}	Maximum oxygen consumption
W_{max}	Maximum aerobic power output (Watt)

List of attachments

List of tables

List of figures

Table of contents

1.0 Introduction

Sports scientists and coaches are continuously trying to develop training regimes to improve athletes' cycling performance (Mujika & Laursen, 2012). Performance in endurance sports is mainly determined by maximum oxygen consumption (VO_{2max}), fraction utilization of VO_{2max}, and work efficiency/economy (Coleman, 2012; Joyner & Coyle, 2008; Basset & Howley, 2000). Hence, to increase performance for endurance athletes, these determinants should be targeted. The effect of endurance training on endurance performance is well known (Laursen & Jenkins, 2002; Jones & Carter, 2000). Additionally, research has supported the effect of concurrent strength and endurance training on determinants of endurance performance (Rønnestad & Mujika, 2014; Tanaka & Swensen, 1998).

Research on concurrent endurance and strength training in cycling has focused on the determinants of endurance performance. VO_{2max} does not seem to be affected either positively or negatively by adding strength training to regular endurance training in cyclists (Rønnestad, Hansen, & Holland, 2015; Aagaard et al., 2011; Rønnestad, Hansen, & Raastad, 2011; Sunde, Støren, & Bjerkaas, 2010; Rønnestad, Hansen, & Raastad, 2010a; Levin, McGuigan, & Laursen, 2009). The lactate threshold (LT) is associated with the fraction utilization of VO_{2max}. Studies that have intervened with concurrent endurance and strength training and measured LT, show either no effect (Aagaard et al., 2011; Sunde et al, 2010; Jackson, Hickey, & Reiser, 2007), or a positive effect on the LT (Rønnestad et al., 2015; Rønnestad et al., 2010a). For cycling efficiency/economy, adding strength training to regular endurance training has shown both positive effect (Barrett-O'Keefe, Helgerud, & Wagner, 2012; Louis, Hausswirth, & Easthope, 2012; Rønnestad et al., 2011; Sunde et al., 2010), and no effect (Rønnestad et al., 2015; Aagaard et al., 2011; Rønnestad et al., 2010a).

Most studies assessing the effect of concurrent strength and endurance training on cycling performance have used traditional strength training (Rønnestad & Mujika, 2014). Little is known about concurrent endurance training and low cadence cycling (LCC) or eccentric cycling (ECC). LCC is a common training method among Norwegian cyclists, with the intention that higher pedal force may lead to improved performance (Kristoffersen, Gundersen, & Leirdal, 2014). However, the literature is scarce and conflicting regarding the effect of LCC on performance determinants and performance in cyclists (Kristoffersen et al., 2014; Nimmerichter, Eston, & Bachl, 2012; Gergley, 2011; de Araújo, Vinicius, & Figueira, 2011; Paton, Hopkins, & Cook, 2009).

Similarly, few studies have investigated the effect of ECC on strength development in trained individuals. Most of the ECC-literature have had a rehabilitation focus (Isner-Horobeti, Dufour, & Vautravers 2013). Some of the improvements seen after ECC are improved quadriceps strength (LaStayo, Marcus, & Dibble, 2011; Mueller et al., 2009; Gerber, Marcus, & Dibble, 2007b; LaStayo, Ewy, & Pierotti, 2003a; LaStayo, Pierotti, & Pifer, 2000, LaStayo, Reich, & Urquhart, 1999), hypertrophy (Leong, McDermott, & Elmer, 2014; LaStayo et al., 2011; Gross, Lüthy, & Kroell, 2010; Mueller et al., 2009; Marcus, Smith, & Morrell, 2008; Gerber, Marcus, & Dibble, 2007a; LaStayo et al., 2003a; LaStayo et al., 2000), leg spring stiffness (Elmer, Hahn, & McAllister, 2012), pennation angles (Leong et al., 2014), eccentric muscle coordination (Mueller et al., 2009), and maximum aerobic power output (W_{max}) (Leong et al., 2014; Elmer et al., 2012).

Isner-Horobeti and co-authors (2013) states in the conclusion of their review article on eccentric training: "*although promising, eccentric training needs to be further explored in order to broaden our understanding of the underlying physiology to better help athletes, patients, coaches and clinicians to take full advantage of the eccentric exercise training modalities*" (p.506). Therefore, it is interesting to investigate whether a training program applied to trained individuals, consisting of both endurance training and ECC or LCC, would have an effect on strength development, muscle thickness, determinants of cycling performance, or cycling performance itself.

The current thesis was written as part of a master degree in health and physical activity; however, due to the nature of the project, the main topic is endurance performance. As my personal educational background is within health and physical activity the topic is also presented and discussed in a health perspective with focus on rehabilitation.

2.0 Theory

2.1 Determinants of cycling performance

Joyner and Coyle (2008) have presented the relations between the different factors contributing to performance velocity or power in their performance model. The three highlighted determinants of cycling performance are 1) Aerobic capacity represented as VO_{2max} and fraction utilization of VO_{2max}, 2) Cycling efficiency/economy, and 3) Anaerobic capacity.

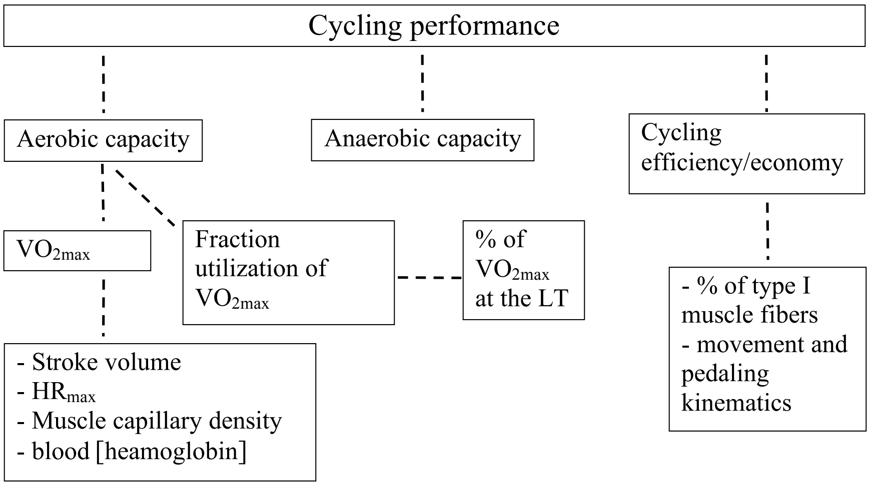

Figure 1: Model of physiological variables affecting cycling performance. Modified based on the Joyner and Coyle performance model (2008). HR_{max}=maximum heart rate. VO_{2max}=maximum oxygen consumption. LT=lactate threshold.

2.1.1 Maximum oxygen consumption and maximum aerobic power output

VO_{2max} is defined as ”*the highest rate at which oxygen can be taken up and utilized by the body during severe exercise*” (Basset & Howley, 2000). VO_{2max} is determined by three or four central factors and one peripheral factor. The central factors are the maximum stroke volume and maximum heart rate (HR_{max}) (cardiac output), O_2 carrying capacity (blood [heamoglobin]), and sometimes pulmonary diffusing capacity (in elite athletes, moderately high altitudes, or certain conditions). Improvements in VO_{2max} from physical activity, is mainly a result of increased maximum stroke volume (Basset & Howley, 2000). The peripheral factor is determined by skeletal muscle characteristics: peripheral diffusion gradients, mitochondrial enzyme levels, and capillary density (Joyner & Coyle, 2008; Basset & Howley, 2000). Increased muscle capillary and mitochondrial density are commonly observed adaptations to regular high intensity training (Henriksson & Sundberg, 2008).

Performance in endurance sports are related to high VO_{2max} values in heterogeneous groups (Bentley, McNaughton, & Thompson, 2001; Paavolainen, Nummela, & Rusko, 2000), and we typically see high VO_{2max} in endurance athletes (Saltin & Åstrand, 1967). However, in homogenous groups of athletes with similar VO_{2max} and performance, a high VO_{2max} does not necessarily correspond to the best endurance performance (Lucía, Hoyos, & Pérez, 2004; Coyle et al., 1991). Hence, other physiological variables such as fraction utilization of

VO_{2max}, work efficiency/economy, and anaerobic capacity may contribute to performance for these athletes.

W_{max} is the highest power output (Watt), that can be held during an incremental cycling test. It is typically measured as the mean power output during the last two minutes or the last minute of a VO_{2max}-test (Rønnestad et al., 2011, 2015). W_{max} is a strong predictor of cycling performance (Hawley & Noakes, 1992), as it is related to VO_{2max}, cycling economy, anaerobic capacity, and neuromuscular characteristics (Jones & Carter, 2000).

2.1.2 Lactate threshold

Blood lactate concentration ($[La^-]_b$) is one of the most frequent measured parameters in performance testing of athletes (Goodwin, Harris, & Hernández, 2007). Some perceive the LT to be the strongest predictor of endurance performance (Sjödin & Svedenhag, 1985; Hagberg & Coyle, 1983; Sjödin & Jacobs, 1981). During physical activity above a certain intensity, $[La^-]_b$ is elevated as a normal response to physical exhaustion (Goodwin et al., 2007). At an incremental exercise test the $[La^-]_b$ elevates rapidly at high intensity, causing a breakpoint between $[La^-]_b$ and the work rate (Goodwin et al., 2007). This breakpoint is called the lactate threshold (LT), defined as "*a key exercise intensity above which the body is under significantly more stress, with accelerated use of carbohydrate stores*" (Coleman, 2012, p.8).

As shown in figure 1, the aerobic capacity is influenced by VO_{2max} and the fraction utilization of VO_{2max}. The fraction utilization of VO_{2max} is strongly associated with endurance performance (Impellizzeri, Marcora, & Rampinini, 2005; Coyle et al., 1991), with increased relevance at longer competition durations (Davies & Thompson, 1986). The LT is an indicator of the fraction utilization of VO_{2max}, and should optimally be expressed as percentage of VO_{2max} (Basset & Howley, 2000). The LT may also be expressed as VO_2 or power output (Watt) (Joyner & Coyle, 2008; Basset & Howley, 2000; Basset & Howley, 1997). Both VO_2 (Coyle et al., 1991) and power output (Bentley, Wilson, & Davie, 1998; Coyle et al., 1991) at the LT are related to cycling performance and are better predictors of endurance performance than VO_{2max} in trained cyclists (Coyle et al., 1991). Endurance training can improve performance by decreasing the accumulation of lactate at a given VO_2 (Basset & Howley, 2000). An elevated LT means that the individual can work on a higher power output (Watt) or fraction of VO_{2max} before accumulating lactate in the muscles

(Bursztyn, 1990). In endurance trained athletes, the LT may be elevated to 85 percent of VO_{2max}, or even higher (Bursztyn, 1990).

Onset of blood lactate accumulation (OBLA) is the exercise intensity at which $[La^-]_b$ reaches a set value, most often set to 4 millimole per liter (mmol/L), although other values are also used (Bursztyn, 1990; Sjödin, Jacobs, & Svedenhag, 1982). At a $[La^-]_b$ of 4 mmol/L, muscle and $[La^-]_b$ are found to be positively correlated, which they are not at higher or lower values of $[La^-]_b$ (Jacobs & Kaiser, 1982). OBLA is an indirect approach of measuring the LT, consequently the method has some limitations. A set OBLA value of 4 mmol/L assumes that everyone's LT is at 4 mmol/L, ignoring the individual variability of the LT (MacIntosh, Esau, & Svedahl, 2002). However, studies show close relations between OBLA (at 4 mmol/L) and endurance performance (Santos-Concejero, Granados, & Bidaurrazaga-Letona, 2013; Sjödin & Jacobs, 1981). Additionally, the LT is considered highly reproducible (r=0.90) when using similar procedures under similar physiological conditions (Dickhuth, Yin, & Niess, 1999).

2.1.3 Cycling efficiency/economy

Work efficiency is the ratio of mechanical work done to the total energy expended (Basset & Howley, 2000), reported as percentage of the total energy expenditure (Hopker, Passfield, & Coleman, 2009). Applied to cycling, the term *cycling efficiency* is used. Improvements in cycling efficiency makes it possible to derive the same power output for the same amount of time with a lower energy cost (Coleman, 2012). Cycling efficiency is closely associated with cycling economy, which is measured as the oxygen cost of working at a specific power output or moving a certain distance (Basset & Howley, 2000).

Cycling efficiency/economy are related to endurance performance in cycling (Hopker et al., 2009; Lucía, Hoyos, & Pérez, 2002; Horowitz, Sidossis, & Coyle, 1994). Hence, due to increases in cycling efficiency/economy, a cyclist may increase performance without having improvements in aerobic or anaerobic abilities. Cycling efficiency seems to have a substantial inter-individual variability in well-trained cyclists (Coyle, Sidossis, & Horowitz, 1992; Coyle et al., 1991). Improving the cycling efficiency is therefore of big interest in elite cyclists, and research suggest that cycling efficiency/economy can affect performance by compensating for a relatively low VO_{2max} (Lucía et al., 2002).

Currently, there is little understanding of how to train work efficiency/economy, and studies investigating efficiency/economy with regards to cycling are limited and contradictory.

Hopker and colleagues (2009) suggest in their review on the effect of training on cycling efficiency, that due to type II errors in some studies, as well as using a cross-sectional design, some researchers (Moseley, Achten, & Martin, 2004; Nickleberry & Brooks, 1996) have wrongly assumed that training has no impact on cycling efficiency. On the contrary, Hopker and colleagues suggest that training improves cycling efficiency, especially if it is carried out at high intensities. It has been suggested that improved cycling efficiency might be related to changes in muscle fiber distribution towards a greater percentage of Type I muscle fibers (Hopker et al.,2009; Horowitz et al., 1994; Coyle et al., 1992; Coyle et al., 1991). Furthermore, a high proportion of Type I muscle fibers has been related to cycling performance (Horowitz et al., 1994).

Additionally, biomechanical factors in the pedal stroke, such as movement and pedaling kinematics have been associated with cycling efficiency (Cannon, Kolkhorst, & Cipriani, 2007; Korff, Romer, & Mayhew, 2007). Cyclists self-selected pedaling technique showed to be more mechanically efficient than a dorsiflexion pedaling technique (Cannon et al., 2007), and pulling the pedal during the upstroke gave greater mechanical effectiveness than other pedaling techniques (Korff et al., 2007). However, despite greater mechanical effectiveness, the cycling efficiency was lower when pulling the pedal during the upstroke compared to other pedaling techniques, suggesting that mechanical effectiveness is not indicative of cycling efficiency across pedaling techniques (Korff et al., 2007). Finally, it has been suggested that cycling efficiency may be affected by body size, related to fatigue and heat retention/removal and how much weight the cyclist has to move (Coleman, 2012). A larger body size and limb mass might cause a higher energy cost and thereby a lower cycling efficiency.

Anaerobic capacity

Most of the metabolic energy during cycling competitions is derived from aerobic sources due to the long race time and therefore predominantly submaximal intensities (Coleman, 2012). Still, there is always an anaerobic component in cycling races, especially in those of shorter duration (Gastin, 2001). Secondary to the three main determinants of endurance performance, anaerobic capacity is important for performance in sprints to break away from a group, or sprinting to the finish line (Faria, Parker, & Faria, 2005). In order to limit the complexity of the thesis' focus area, a test of anaerobic capacity was not included, and anaerobic capacity will not be discussed any further in the thesis.

2.2 Strength training

2.2.1 Cycling performance

Adding strength training to the training program of cyclists has been debated. Keeping a low weight is important for cyclists in order to use less energy to move the body. Strength training may cause an increase in body mass and muscle mass (Folland & Williams, 2007). Therefore, for some cyclists, a fear of increasing weight following strength training has been a barrier for introducing this type of training. The effect of strength training on factors important for cycling performance has been investigated. Strength training is defined as "*any exercise aimed to develop or maintain our ability to create maximal force (torque) at a specific or predetermined velocity* (Raastad, Paulsen, & Refsnes, 2010, p.121, translated).

Concurrent endurance and strength training has shown to be conflicting, with attenuated effects on the development of muscle hypertrophy (Putman, Xu, & Gillies, 2004), strength gains (Izquierdo, Häkkinen, & Ibanez, 2005) and neural adaptation (Häkkinen et al., 2003) compared to strength training alone. Several studies support these findings; however still some studies report no negative effects on adaptation to strength training with concurrent endurance and strength training (Shaw, Shaw, & Brown, 2009).

Increased muscle strength is a result of hypertrophic and/or neural adaptations (Kraemer & Ratamess, 2004). After 12 weeks of heavy strength training performed together with endurance training in 11 well-trained cyclists, increased thigh muscle cross sectional area (CSA) was found, with no increase in body weight (Rønnestad et al., 2010a). Similar findings have been found in other studies on triathletes and cross-country skiers (Millet, Jaouen, & Borrani, 2002; Hoff, Helgerud, & Wisløff, 1999). This is likely due to the intervention being conducted after a recovery phase, where some fat mass is being replaced by muscle mass, resulting in no change in net body mass (Rønnestad et al., 2010a). Other studies have also found improvements in strength without increasing body weight (Rønnestad et al., 2011; Sunde et al., 2010). These studies did not test hypertrophy, and in one of the studies the authors suggested that the strength improvements were mainly due to neural adaptations (Sunde et al., 2010). On the other hand, there are studies reporting increased lean body mass (2-3%) after concurrent strength and endurance training (Rønnestad et al., 2015; Aagaard et al., 2011). However, these gains are considerably lower than those observed after strength training only (Aagaard et al., 2001).

Studies investigating the effect of strength training in cyclists have shown conflicting results. Several studies reported improved performance after implementing strength training in addition to regular endurance training (Rønnestad et al., 2015; Aagaard et al, 2011, Rønnestad et al., 2011; Rønnestad et al., 2010a). However, other studies report no effect on performance after concurrent strength and endurance training. (Psilander, Frank, & Flockhart, 2015; Levin et al., 2009; Jackson et al., 2007; Bastiaans, van Diemen, & Veneberg, 2001; Bishop, Jenkins, & Mackinnon, 1999).

The conflicting results may be partly related to the design of the intervention; whether they have done heavy or explosive strength training. Heavy strength training can be defined as "*all training performed with the purpose of increasing the capability to produce maximum force in slow movements or in pure maximal isometric muscle actions*" (Raastad et al., 2010, p.14, translated). It is performed at an intensity of more than 80 percent of 1 repetition maximum (RM) (Raastad et al., 2010). Explosive strength training on the other hand, may be defined as "*exercise with external loading of 0-60 percent of 1 RM and maximal mobilization in the concentric phase*" (Rønnestad & Mujika, 2015, p.603).

If strength training positively effects cycling performance, it should be evident through changes in VO_{2max}, LT, work efficiency/economy, and/or anaerobic capacity (Vikmoen, 2015). Concurrent strength and endurance training in cyclists does not seem to increase VO_{2max} more than endurance training performed alone (Rønnestad et al., 2015; Rønnestad et al., 2011; Aagaard et al., 2011; Sunde et al., 2010; Rønnestad et al., 2010a; Levin et al., 2009). Neither does any of these studies find negative effects of strength training on VO_{2max}. Therefore, the possible positive effects of strength training have to be related to other determinants of performance.

Whether muscle strength improves W_{max} is not clear. Some studies found increased W_{max} after ECC (Leong et al., 2014; Elmer et al., 2012), while another study found no such improvement (Gross et al., 2010). Studies report improved W_{max} after maximal leg-strength training (5 RM) in untrained individuals (Loveless, Weber, & Haseler, 2005) and after concurrent strength and endurance training in elite cyclists (Rønnestad et al., 2015) and well-trained cyclists (Rønnestad et al., 2010a; Sunde et al., 2010). While other studies found no improvements in W_{max} after concurrent strength and endurance training (Levin et al., 2009), or after replacing a part of cyclists' endurance training with explosive strength training (Bastiaans et al., 2001).

Few studies to my knowledge, have investigated the effect of concurrent strength and endurance training for trained cyclists regarding percentage of VO_{2max} at the LT. However, those who have show no changes (Rønnestad et al., 2015; Sunde et al, 2010). The LT may also be expressed as the velocity or power output at the LT. Also here, most studies report no changes after concurrent strength and endurance training in cyclists (Aagaard et al., 2011; Sunde et al., 2010; Jackson et al., 2007). However, some indicate positive effects on power output at the LT (Rønnestad et al., 2015; Rønnestad et al., 2010a).

The effect of concurrent strength and endurance training on cycling efficiency/economy in cyclists is unclear. Most studies are conducted with participants in a non-fatigue state. These studies report conflicting results, whereas some show improved cycling efficiency/economy (Louis et al., 2012; Barrett-O'Keefe et al., 2012; Sunde et al., 2010), others show no effect (Rønnestad et al., 2015; Aagaard et al., 2011; Rønnestad et al., 2010a; Rønnestad, Hansen, & Raastad, 2010b; Jackson et al., 2007; Bastiaans et al., 2001). It seems as improved cycling efficiency/economy is dependent on the cyclists' performance level (Vikmoen, 2015). In general, the cyclists in the studies that showed positive effects of concurrent training were of lower performance level (Barrett-O'Keefe et al., 2012; Louis et al., 2012; Sunde et al., 2010) than those who did not experience any improvements in cycling efficiency/economy (Rønnestad et al., 2015; Aagaard et al., 2011; Rønnestad et al., 2010a; Rønnestad et al., 2010b;). Hence, elite cyclists may already have highly optimized cycling efficiency/economy.

Despite conflicting results on the effect of concurrent strength and endurance training on cycling efficiency/economy, it seems as the addition of strength training might have a positive effect. It is likely that both performance level of the cyclists as well as the design of the strength training program will impact on this relation. Improved cycling economy has been shown to be related to improved cycling performance (Sunde et al., 2010). However, improved performance has also been reported after concurrent training without improvements in cycling efficiency/economy (Aagaard et al., 2011; Rønnestad et al., 2010a; Rønnestad et al., 2010b). Therefore, improved cycling efficiency/economy might not be the only factors after concurrent training associated with improved cycling performance.

2.2.2 Eccentric strength training

Eccentric muscle work is dominant in braking movements such as downhill walking/running or alpine skiing, and activities where absorbed energy is recovered for power enhancement such as sprinting, running, jumping, or throwing (Jindrich, Besier, & Lloyd, 2006). The eccentric muscle work used in these activities is characterized by a lengthening of the muscle. This lengthening occurs when the momentary force produced by the muscle itself is exceeded by the external force applied to the muscle (Lindstedt, Reich, & Keim, 2002).

For endurance sport athletes, endurance training is the main focus; however, integration of strength training into the training program has shown to be of importance for performance (Vogt & Hoppler, 2014). It is speculated whether eccentric strength training may cause additional improvements in strength and performance of athletes in different sports (Isner-Horobeti et al., 2013). Eccentric muscle work can be done with one's own body weight, weight machines, barbells, dynamometers, as well as different ergometers (Vogt & Hoppler, 2014).

The muscles can generate more force when being lengthened in eccentric muscle work, causing an overload of the muscular system (Isner-Horobeti et al., 2013). This overload occurs at a very low energy cost with a lower metabolic demand (lower VO_2) than concentric muscle work (Isner-Horobeti et al., 2013). Additionally, when eccentric and concentric training are performed at a similar mechanical power, the eccentric training demands less of the cardiovascular system (cardiac output and HR) (Isner-Horobeti et al., 2013; LaStayo et al., 1999). Due to the low metabolic and cardiovascular demands, eccentric training is being studied with regards to the effect on performance, injury prevention, and rehabilitation (LaStayo, Woolf, & Lewek, 2003b).

Eccentric muscle work requires recruitment of a larger area of the cortex, and is therefore a more complex neuromuscular task than concentric muscle work (Kwon & Park, 2011). Vogt and Hoppler (2014), concludes in their review on eccentric exercise, that eccentric training can improve maximal muscular strength, power development, coordination in eccentric movements, as well as having the potential to shift peak torque (rightwards). The rightwards shift of peak torque, causes peak torque to be produced at a longer muscle length giving optimal tension development which is important for performance as well as injury prevention (Cowell, Cronin, & Brughelli, 2012).

The body seems to respond to the eccentric muscle work in a higher degree than through other muscle work (Enoka, 1996). It adapts to the eccentric stimuli through structural adaptations in the muscles such as hypertrophy and an increase in the proportion of Type II muscle fibers (Isner-Horobeti et al., 2013), as well as an activation of an inflammatory response, and modification of the neural networks controlling the movements (Enoka, 1996). Strongest effects are found in untrained or trained individuals (Cowell et al., 2012; Guilheim, Cornu, & Guevel, 2010; Roig, O'Brien, & Kirk, 2009). However, effects are also found for highly trained athletes (Gross et al., 2010; Friedmann-Bette et al., 2010; Sheppard, Hobson, & Barker, 2008).

2.2.3 Eccentric cycling

The first eccentric cycle for the lower limbs was used in the study of Abbot, Bigland, and Ritchie in 1952. The eccentric cycle was made up of two bicycle ergometers which were placed back to back, and connected by a chain. The cyclist pedaling forward were doing concentric muscle work, while the muscles of the other cyclists were being forcibly stretched and thereby doing eccentric muscle work. Thy found that concentric muscle work costs more than eccentric muscle work, measured through VO_2, and that the difference increases with increased cadence.

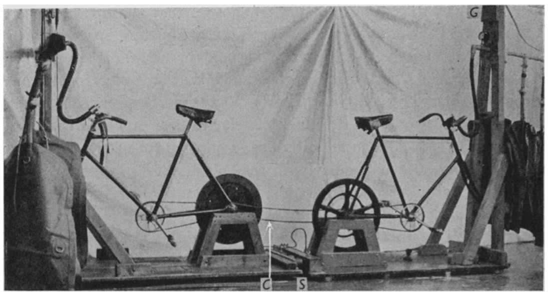

Figure 2: The first eccentric cycle (Abbot, Bigland, & Richie, 1952).

The eccentric ergometer has developed over the last decade. Studies have used semi-seated leg-cycle ergometers (Dufour, Lampert, & Doutreleau, 2004) or *eccentric steppers* (LaStayo, Larsen, & Smith, 2010; Marcus et al., 2008), and arm-cycle ergometers (Elmer, Danvind, & Holmberg, 2013). These ergometers have pedals that move towards the individual, making the muscles work eccentrically when trying to break the movement. The newest eccentric ergometer (Cyclus2 Eccentric Trainer, RBM elektronik-automation GmbH, Leipzig, Germany), makes it possible to connect the athletes own bike to the ergometer.

Training programs should be specific to the requirements of the sport (Vogt & Hoppler, 2014). Therefore, most available research on the effect of ECC is applied in other sports than cycling, such as alpine skiing, and sports requiring jumps and sprints where eccentric strength is important (Vogt & Hoppler, 2014). Concentric movements are dominant in cycling; however, eccentric training done in the cycling movement will activate the same muscles as used when cycling. These are the knee extensors and flexors, hip extensors and flexors, and ankle plantar flexors (Ericson, Bratt, & Nisell, 1986). Most of the ECC-studies have used a semi-seated cycling ergometer. In the semi-seated position, the individual sit with the back resting backwards, and the legs cycling forwards more horizontal than vertical causing a smaller hip-angle, and the muscles working differently than on a regular bike. With the Cyclus2 Eccentric Trainer, the muscles work with the same joint-angles and the same forces of gravity as when performing regular cycling exercise.

Most studies investigating ECC have been conducted with few participants, which may reduce the power of the results. It is important to keep this in mind when interpreting the following findings. The training work rate (Watt) during ECC can be seven times higher than during concentric cycling, without causing muscle damage or pain (LaStayo et al., 1999). After six weeks, isometric strength increased (33%) in the ECC-group. No significant strength gains were seen after concentric cycling at similar training heart rate (HR) and cadence (50-60 RPM) (LaStayo et al., 1999). In another study, muscle hypertrophy (52%) occurred after eight weeks in the ECC-group, while the concentric cycling-group experienced no significant changes (LaStayo et al., 2000).

Other studies have also found significant effects of ECC on hypertrophy (Leong et al., 2014; LaStayo et al., 2011; Gross et al., 2010; Mueller et al., 2009; Marcus et al., 2008; Gerber et al., 2007a; LaStayo et al., 2003a; LaStayo et al., 2000), quadriceps strength (LaStayo et al., 2011; Gerber et al., 2007b; LaStayo et al., 2000), leg spring stiffness (Elmer et al., 2012), pennation angles (Leong et al., 2014), eccentric muscle coordination (Mueller et al., 2009), determinants of jumping performance (Elmer et al., 2012; Gross et al., 2010; Gerber et al., 2007b), and W_{max} (Leong et al., 2014; Elmer et al., 2012).

Leong and co-authors (2014), designed a study to investigate the effect of chronic ECC on muscle structure and function one and eight weeks following an eight-week intervention. They found significant improvements in m. rectus femoris and m. vastus lateralis thickness and pennation angles, as well as in W_{max}. Especially interesting was the different findings in W_{max} at one and eight weeks post-training of 5 percent (SD=1) and 9 percent (SD=2) respectively. The authors suggest that the lower increase in W_{max} at one week than at eight weeks post-training might be due to muscle-remodeling after the high intensity eccentric training causing suppressed muscle force. The authors do not state whether they were controlling for training done between the intervention period and testing eight weeks after.

To this date, there are no common agreement on how to measure intensity when training on an eccentric ergometer. Precaution should be taken concerning intensity, since eccentric training at a supramaximal level may cause pain and exercise-induced muscle damage (EIMD) or delayed-onset muscle soreness (DOMS) (Isner-Horobeti et al., 2013; Cleak & Eston, 1992). A session of single-leg ECC at 40 percent of single-leg W_{max}, performed at 60 RPM caused significant inhibition of W_{max} 24 and 48 hours post training in recreational cyclists (Elmer, McDaniel, & Martin, 2010). In the same study, DOMS measured on the VAS 10 point scale increased significantly from baseline, with highest scores 48 hours after. EIMD symptoms usually peaks 12 to 72 hours after the eccentric training bout, and may last 5-7 days before the muscles are recovered (Isner-Horobeti et al., 2013). However, if the eccentric training is done regularly, “the repetition bout effect” occurs, whereas EIMD is progressively reduced, likely as a result of neural, mechanical, and cellular adaptations (Isner-Horobeti et al., 2013; Paddon-Jones, Muthalib, & Jenkins, 2000).

A common method of targeting intensity during ECC is working on a fraction of HR_{max} (Leong et al., 2014; Elmer et al., 2012; LaStayo et al., 2000). However, cardiac output (HR x stroke volume) and oxygen uptake are much lower during ECC than concentric cycling despite similar power output and cadence (Dufour et al., 2004; Bigland-Ritchie & Woods, 1976, Knuttgen & Klausen, 1971), without increasing the anaerobic metabolism (Isner-Horobeti et al., 2013). The lower cardiac output is due to a lower heart rate (HR) rather than stroke volume (Dufour et al., 2004; Henriksson, Knuttgen, & Bonde-Petersen, 1972). Hence, estimating intensity based on HR from a concentric cycle test may be inaccurate.

Perceived exertion during a concentric test can be used to individualize intensity of ECC, in preconditioning when starting ECC training (Laroche, Joussain, & Espagnac, 2013). However, compared with concentric training, perceived exertion has shown to be considerably lower during eccentric training at the same workload (Henriksson et al., 1972). Using VO_2 and rate of perceived exertion (RPE) to target intensity caused very little muscle soreness and no muscle injury (LaStayo et al., 1999). Other studies have used Borg scale for the lower extremities (Marcus et al., 2008) or Borg CR10 scale (Borg, 1982; Noble, Borg, & Jacobs, 1983) to target training intensity starting at very very light intensity with a gradual increase over time (LaStayo et al., 2011; Gerber et al., 2007a, 2007b).

2.2.4 Eccentric cycling in a health perspective

Most studies on ECC have been conducted in a health perspective with rehabilitation as the main focus. The cycle ergometers have either been semi-seated or arm-cycle ergometers. The aim of these studies has been to increase knowledge on how to maintain or restore physical capacity and quality of life for older adults and individuals with different pathological conditions. Eccentric exercise is safe and feasible for healthy as well as vulnerable individuals, as long as the intensity is individually adapted and gradually increased (Isner-Horobeti et al., 2013).

As mentioned, eccentric exercise enables the individual to perform high loads on the musculoskeletal system with minimal stress on the cardiovascular system and with a low energy cost (Isner-Horobeti et al., 2013; LaStayo et al., 1999). Therefore, eccentric exercise is suitable for individuals of low cardiovascular abilities such as frail older adults or vulnerable individuals in a rehabilitation setting. In addition, as noted, less trained individuals respond better to eccentric loads than well-trained individuals (Cowell et al., 2012; Guilheim et al., 2010; Roig et al., 2009).

Aging is associated with a gradual degeneration process of physiological functions, causing loss of muscle mass and muscle strength, and reduced ability to perform tasks of daily living (Cruz-Jentoft et al., 2010). The degeneration process is associated with an increased risk of falls and fractures, as well as loss of independence (Cruz-Jentoft et al., 2010). Injuries after falls are a major economic cost for the society (Corso, Finkelstein, & Miller, 2006), and the most common cause of injury-related death for individuals over 75 years (Masud & Morris, 2001). Therefore, interventions to slow down the degeneration process is of great importance.

Older adults had higher strength gains after eccentric strength training than after conventional strength training (Reeves, Maganaris, & Longo, 2009). In this population, ECC has shown to cause hypertrophy (Mueller et al., 2009; LaStayo et al., 2003a), and improve isometric leg strength (Mueller et al., 2009; LaStayo et al., 2003a), balance performance (LaStayo et al., 2003a), eccentric muscle coordination (Mueller et al., 2009), and mobility (LaStayo et al., 2003a). ECC has also shown great effects for health related variables in individuals suffering from cardiorespiratory diseases (Rooyackers, Berkelijon, & Folgering, 2003), metabolic disorders (Marcus et al., 2008), neurological pathologies (Dibble et al., 2009), cancers (LaStayo et al., 2010, 2011), and after injuries (Gerber et al., 2007b).

ECC may be trained together with endurance training for optimal health benefits (Raastad et al., 2010). Participants with type 2 diabetes trained either concurrent ECC and endurance training or only endurance training for 16 weeks (Marcus et al., 2008). The result showed significantly decreased mean glycosylated hemoglobin and mean thigh intramuscular fat CSA, and significantly increased 6-minute walking distance in both groups. The ECC-group had additional improvements in thigh lean tissue and BMI. The improvements in thigh lean tissue is important for diabetics since it might increase the protein reserve, resting metabolic rate, exercise tolerance, and functional mobility (Marcus et al., 2008).

2.2.5 Low cadence cycling

A common definition of LCC was not detected when going through the literature on different cadence in cycling. On the other hand, a cadence of 90 RPM is considered high, and is believed to be optimal for professional cyclists during regular endurance training or in competition (Foss & Hallén, 2005a; Lucía, Hoyos, & Chicharro, 2001). Hence, LCC is a lower cadence than 90 RPM. In the relevant literature presented here, LCC ranged between 40-70 RPM. Research on the effect of LCC in trained cyclists are limited and conflicting.

To my knowledge, the study conducted by Kristoffersen and co-authors (2014) is the largest study on LCC, with regards to duration and population size. They used a cadence of 40 RPM, which is the lowest found cadence studied in this context. Twenty-two well-trained veteran cyclists trained twice a week for 12 weeks at moderate intensity (73-82% of HR_{max}). The LCC-group (n=11) trained intervals at 40 RPM, while the control group (n=11) trained intervals at a freely chosen cadence. Interval training at a cadence of 40 RPM did not cause any significant improvements in cycling performance, aerobic capacity, efficiency, power output, or leg strength for the cyclists.

On the contrary, another study found greater improvements in cycling performance in the LCC-group (60-70 RPM) than in the high cadence-group (110-120 RPM) (Paton et al., 2009). In this study, 18 road cyclists replaced part of their training with eight sessions of 30 minutes over four weeks. Both groups did sets of explosive single-leg jumps, and high intensity cycling sprints on an ergometer at different cadence. The authors suggested that the greater performance improvements in the LCC-group might have been related to a higher production of pedal force, and may be associated with elevated testosterone levels and VO_{2max}. Similarly, another study compared cycling interval training at 60 RPM uphill with interval training at 100 RPM on ground level in cyclists (Nimmerichter et al., 2012). Both groups had significant increases in cycling performance measured as power output; however, the LCC-group improved more in power output than the 100 RPM-group, and the LCC-group improved performance at both flat and uphill 20 minute all-out. The authors suggested that the higher forces found during cycling intervals at 60 RPM, than at 100 RPM, are potentially beneficial to improve performance.

Less strength loss was found after high intensity aerobe exercise performed at 50 RPM than after 100 RPM, when testing strength directly after the aerobe exercise (de Araújo et al., 2011). The authors therefore suggested to train aerobe exercise with low pedal cadence when the aerobe exercise precedes strength training, in order to minimize strength loss. However, they did not study the effect on muscle strength in a longer perspective. Similarly, another study (Gergley, 2011), suggested that individuals whose main aim is to increase muscle strength, but simultaneously wishes to train endurance training, may benefit from cycling at a lower cadence. In this study, the group training concurrent strength and LCC at 70 RPM increased more in strength over nine weeks, than the group training concurrent strength and cycling at 90 RPM at the same aerobe intensity.

3.0 Aim and hypotheses

How does concurrent endurance training and ECC twice a week over 10 weeks alter determinants of endurance performance in trained individuals?

Hypothesis 1: The ECC-group will have a greater development of eccentric strength and muscle thickness than the LCC-group.

Hypothesis 2: The ECC-group will have better effects on cycling performance (20 minutes all-out), cycling economy, and power output at the LT than the LCC-group.

Hypothesis 3: VO_{2max} and W_{max} will increase to the same degree in both groups.

4.0 Method

4.1 Participants

Descriptive data of the 23 men who participated in the study are presented in table 1. The recruitment of participants for the study was done through different forms of social media as well as direct contact with Lillehammer Cycling Club. The inclusion criteria were experience with regular cycle training, and being able to participate in two scheduled training sessions per week. Initially individuals with an expected VO_{2max} of ≥60 mL/kg/min and a finishing time at the Norwegian mountain bike race *Birkebeinerrittet* of less than three hours and 30 minutes were recruited. However, due to a lack of available fit cyclist, we also included nine participants with a lower expected VO_{2max}. The participants were divided into an ECC-group (n=12) and a LCC-group (n=11) based on stratified randomization to control for confounding factors. The participants were matched for age, weight, and values for VO_{2max} and power output (Watt) at the LT measured at pre-test. Since several of the participants were competitive cyclists, some attended a week long training camp abroad during the intervention period (ECC-group: 17%, LCC-group 9%).

Table 1: Participant characteristics at baseline.

	ECC-group mean (SD)	**LCC-group** mean (SD)
Age	36.3 (13.4)	29.4 (10.2)
Weight	76.3 (7.8)	78.0 (6.7)
Endurance training pre-project h/w	8 (3.5)	6 (3.7)
Maximal strength pre-project h/w	2 (2.0)	3 (1.9)
Heavy strength on legs pre-project	58%	55%

Subject characteristics at baseline and during intervention for the eccentric cycling-group (ECC) and the low cadence cycling-group (LCC). The age ranged from 19 to 57 years (mean age 33, SD=12). The table shows group-distribution of age and weight, as well as self-reports of mean hours of weekly endurance training (including heavy, moderate, and light intensity) and maximal strength training during the last 12 weeks pre-project (missing scores for one participant from each group). Additionally, the table shows the percentage of participants who performed heavy strength training on legs between October-November 2015 (self report). Data is presented as mean and standard deviation (SD) where appropriate.

4.2 Study design

The data used in this master thesis are collected in collaboration with the University of Lillehammer (HiL). Data were collected over 11 weeks, from January until March 2016 (figure 2). The intervention period lasted from week 2 until week 10, with a total of 17 planned training sessions per participant. The pre- and post-testing were arranged over one week at week 1 and 11. Two participants performed the pre-testing three weeks before the other participants. These two participants were placed in different groups to control for the confounding factor of testing earlier than the others. All cycling tests were performed on the same electromagnetically braked cycle ergometer (Lode Excalibur Sports, Lode B.V. Groningen, The Netherlands). The ergometer was adjusted to the participants' preferences for height, and angle, as well as horizontal position of the saddle, and height and horizontal position of the handlebar. The same settings were used at all tests.

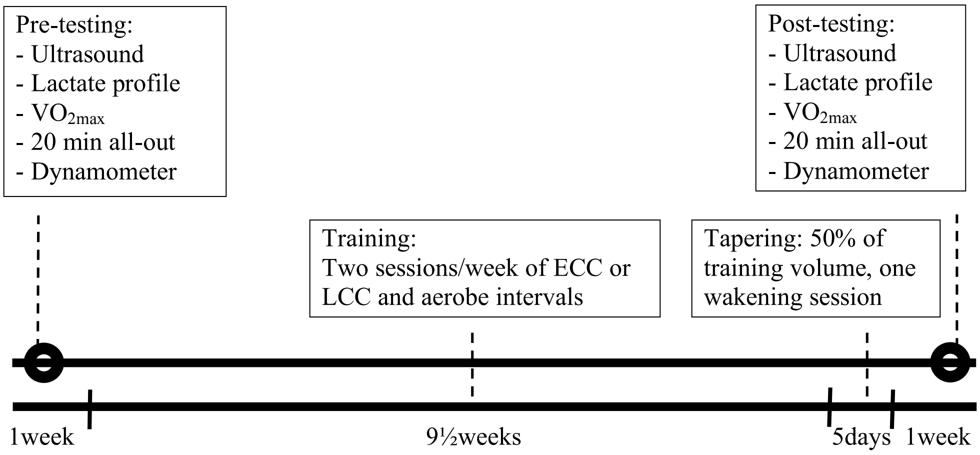

Figure 3: Study protocol. Presenting testing, training, and tapering. VO_{2max}=maximum oxygen consumption.

Figure 3 and 4 show the tests studied in this thesis. The complete study protocol also contained a second day with strength-tests (Air 300 leg press, Keiser Fresno USA) and six and 30 seconds sprint tests. These three tests were performed at week 1, 4, 7, and 11. However, they were not studied in the current thesis, and will not be discussed further. Day one and two of testing were performed on nonconsecutive days. Day one lasted about 120 minutes, with all tests performed on the cycle ergometer. The first test was the blood lactate profile test, followed by the VO_{2max}-test, and the 20 minute all-out test. The first two tests were separated by a 10 minute break, and the last two tests were separated by a 20 minute break. During the breaks the participants performed easy pedaling on the ergometer.

The post-tests were implemented five days after the last training session. The same tests were repeated at post-testing and pre-testing. Each participant completed the tests at the same time of day (±2hours), to avoid influence of circadian rhythm (Teo, Newton, & McGuigan, 2011). At the post-tests, the ultrasound examination was mainly performed at day one of testing (ranging from 0-4 days before) (figure 4).

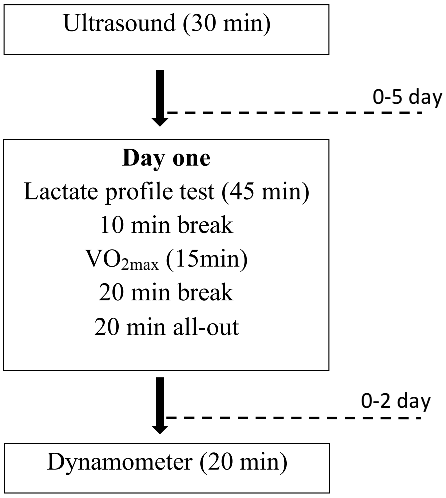

Figure 4: Overview of the protocol for pre- and post-testing. The figure shows the arrangement and duration of tests and breaks. The values at the dotted lines represents time between the tests, 0 meaning the same day. All tests were done in the same order. VO_{2max}=maximum oxygen consumption.

Tapering

To achieve peak performance at post-testing in week 11, the last training session and day one of testing were separated by five days (six days for one participant). In this period, the participants were encouraged to decrease their training volume by 50 percent, as well as performing a training session of five times two minutes aerobic intervals at 93-98 percent of HR_{max} or 17-18 at Borg scale (Borg, 1970; 1982), two days before day one of post-testing (Faria et al., 2005).

4.4 Data collection

4.4.1 Tests

All tests in this project were conducted in the physiological labs at HiL. The temperature in the labs were between 16°-18°C, and the humidity level were 15-20 percent. Only the methods used for collecting data relevant for the research question will be elaborated here. These are the the ultrasound examination, dynamometer test, and all the tests carried out on day one; the blood lactate profile test, the VO_{2max}-test, and the 20 minutes all-out test.

To control for external factors and replicating the testing protocol, we aimed at performing post-tests in the same order, with the same preparations and under the same conditions as the pre-tests. The participants were asked not to drink beverages containing caffeine the last 4 hours before testing, as well as withstanding from any high intensity physical activity the day before testing. Information about food intake at the day of pre-test were collected, and sent out to the participants through e-mail the day before post-tests, asking them to eat the same as they did before the pre-tests. The participants used the same cycling shoes and their own HR-monitor at all tests. A fan was used during the tests to cool down the participants.

The Borg scale (attachment 1) was used to rate perceived exertion during the cycling tests. The scale ranges from 6 to 20, were 6 is equal to no exertion at all and 20 represents maximal exertion (Borg, 1970; 1982). The scale is developed so that ratings of perceived exertion increases linearly with HR and power output on a cycle ergometer (Borg, 1982). The Borg scale is shown to be reliable when used on a healthy population (Skinner, Hutsler, & Bergsteinova, 1973; Noble & Robertson, 1996).

Ultrasound

An ultrasound examination was performed by a trained professional with an ultrasound scanner (Echo Blaster 128, TELEMED, Vilnius, Lithuania), probe (HL9.0/60/128Z-2), and software (Echo Wave II, TELEMED Vilnius, Lithuania). Muscle thickness and pennation angles were measured in m. rectus femoris, m. vastus lateralis, m. vastus medialis, and m. biceps femoris. The procedure lasted approximately 30 minutes and entailed 12-15 images taken with the probe oriented in the longitudinal and the transverse plane perpendicular to the skin. During testing, characteristics on the skin such as moles, as well as area of measures at pre-test were drawn on a transparent paper. Using the same transparent paper at post-test, the tester assured that he measured the same sites at pre- and post-test. The ultrasound examination is considered an appropriate method for measuring muscle mass (Abe et al., 2015; Reeves, Maganaris, & Narici, 2004). In the current thesis, data on mean muscle thickness of m. biceps femoris and m. quadriceps femoris were studied.

VO_2-measure

Ventilation (Ve), breathing frequency (BF) and respiratory exchange ratio (RER) were measured during the blood lactate profile-test and the VO_{2max}-test. The tests were conducted with the participant breathing through a tube connected to a computerized metabolic system with a mixed chamber (Oxycon Pro, Erich Jaeger, Hoechberg, Germany) measuring maximal values for Ve, BF, and RER every 30 seconds. The metabolic system used is considered an accurate system for measuring VO_2 after validation against the Douglas bag method (Foss & Hallén, 2005b). The gas analyzers were calibrated before every test against certified calibration gases of known concentrations. Finally, the flow turbine (Triple V, Erich Jaeger, Viasys Healthcare, Germany) was calibrated before every test with a 3 L, 5530 series calibration syringe (Hans Rudolph Inc, Kansas City, Missouri, USA).

Blood lactate profile

Before starting the test, the participants were weighed, and information about the last meal before the test were collected and noted. The brand and mixture of sports drinks consumed during the test were noted. The sports drinks were weighed at every stage, measuring how much they drank. This information was used at post-test, encouraging them to drink the same amount. The test was conducted following a protocol of increasing the load (Watt) every five minutes. The participants chose the cadence freely. If the participant had done the test before, the same load setup was used again. If not, the load setup had to be adapted based on the participant's weight and physical fitness. The starting load was 125W and increased with 25W or 50W at each stage, aiming at reaching $[La^-]_b$ close to 4.0 mmol/L. $[La^-]_b$ was measured the last 15 seconds of each stage. Blood was taken from the participants fingertip and analyzed for $[La^-]_b$ with a lactate analyzer (Lactate Biosen C-line Clinic, EKF Diagnostics, Cardiff, United Kingdom). The OBLA method was used, stopping the test when reaching $[La^-]_b$ of ≥4.0 mmol/L (Sjödin & Jacobs, 1981).

The participant's LT expressed as power output, VO_2, and percentage of VO_{2max} at 4 mmol/L were calculated based on the last measures through equations in Excel (version 15.20 (160315)). VE, BF, and RER were measured from the 2nd minute until 4 and ½ minute of every stage (Oxycon Pro, Erich Jaeger, Hoechberg, Germany). HR was measured as the mean of the last minute of every stage, and was noted before measuring $[La^-]_b$, to avoid elevated HR not related to the physical effort. Additionally, Borg scale (Borg, 1970; 1982) (attachment 1) and rating of feeling in the legs (attachment 2) were measured at every stage. The blood lactate profile test was followed by a break of 10 minutes, where the participant performed light pedaling with preferred cadence.

Cycling economy

The VO_2 and $[La^-]_b$ measured at every stage during the blood lactate profile test were used to study cycling economy. Most participants were measured at 125W, 175W, and 225W. Only a few participants reached their LT above 275W, giving too few results to measure cycling economy at this power output.

VO_{2max} & W_{max}

The participants could freely choose the cadence themselves during the VO_{2max}-test (usually ~90 RPM). The load was measured in Watt and the starting load was determined by the result in the lactate profile test, starting at a load somewhat lower than the LT. The starting load was usually 150W or 200W. During the test, the load was increased by 25W per minute until complete exhaustion. The test-leader verbally motivated the individual being tested to continue to exhaustion.

We measured HR and Borgs scale (Borg, 1970; 1982) directly after complete exhaustion, as well as HR and $[La^-]_b$ one minute after the end of the test. Ve, BF, and RER were measured every 30 seconds (Oxycon Pro, Erich Jaeger, Hoechberg, Germany). VO_{2max} was calculated as the average of the two highest VO_2 measurements, and W_{max} was calculated as the mean power output of the last minute of the test. The criteria for whether VO_{2max} values were reached, were cycling to exhaustion in addition to two out of the following: RER >1.05 at the end of test, $[La^-]_b$ ≥8.0 mmol/L during the first two minutes after the test (Howley, Bassett, & Welch, 1995) and reported Borg's scale ≥18 (6-20) directly after the test (Hansen, Rønnestad, & Vegge, 2012). The VO_{2max}-test and the 20 minute all-out test were separated by a break of 20 minutes where the participant could go off the cycle ergometer or do light pedaling at preferred cadence.

20 minutes all-out

The 20 minute all-out time trial gives a measure of the mean power output (Watt) the participant can work at for 20 minutes, and is a measure of performance (Paton & Hopkins, 2001). The participants decided their own starting load based on the obtained power output at the LT from the blood lactate profile test, as well as their own perception of what power output they could hold for 20 minutes. During the test, the participants controlled the load (Watt) themselves, increasing the load during the test if possible. The participants were allowed to occasionally stand for short periods, in order to kick up the cadence if needed. Having done this test before is beneficial, since knowing approximately which mean power output one can hold throughout the test increases the chance of reaching one's true potential. $[La^-]_b$ and Borgs scale (Borg, 1970; 1982) were measured every five minutes, while mean power output, HR, and cadence were measured every minute. Amount of water or sports drink consumed were noted during the test.

Isometric & isokinetic torque

The dynamometer (HUMAC NORM, Computer Sports Medicine Inc, Massachusetts, USA) was used to measure isometric torque as well as isokinetic concentric and eccentric torque in the knee flexors and knee extensors. The apparatus increases the load when detecting accelerated contraction speed in the muscles in order to keep the movement at a constant speed. The protocol lasted about 20 minutes and started with testing of isokinetic concentric muscle work; warm-up of five repetitions at 60°/second, 30 seconds break, three repetitions at 60°/second, followed by a one minute break. Warm-up of five repetitions at 180°/second, 30 seconds break, and four repetitions at 180°/second. After a one minute break followed testing of isometric muscle work; two times five seconds of maximum contraction at 60°, separated by a one minute break, and repeated twice at 90°. Finally, the protocol ended with testing of isokinetic eccentric muscle work; two times four repetitions at 60°/second separated by a 30 seconds break. The measures of peak torque during eccentric and concentric knee extension at 60°/second and 180°/second, and isometric knee extension at 60° and 90°were used in this thesis.

4.4.2 Intervention

The intervention period lasted 10 weeks, from January until March. The participants trained two sessions per week following a set protocol, giving a total of 17 sessions for those who had a 100 percent attendance. Each training session was instructed by students from HiL and contained ECC or LCC and aerobic intervals. The training sessions lasted between 105-120 minutes. Adherence to the training sessions were high, with a total of 98 percent (SD=0.62) completing all sessions. In the ECC- and the LCC-group, 97 percent (SD=0.78) and 99 percent (SD=0.30) completed all sessions respectively.

Also, five training sessions of low intensity and long duration (50-120 minutes) were offered for those who wished during the intervention period. The participants were not to do any other strength training of the legs during the 11 weeks. Before starting each training session, the participants were asked to fill out a visual analog scale (VAS 10 point scale) measuring muscle soreness (attachment 3). The scale is made up of four lines of 10 cm, each representing soreness in the front of the thighs, the back of the thighs, gluteus and the calves. After performing a squat, the participant pointed out on the line the amount of soreness, ranging from *no soreness* on the far left, and *maximal soreness* on the far right.

Eccentric cycling or low cadence cycling

Each training session started with a 10 minute warm-up at low intensity. After the warm-up, one group performed ECC and the other performed LCC. At the first session, the ECC-group performed two times two minutes intervals of low intensity to get familiar with the bike, before proceeding with the protocol. ECC and LCC were trained with two minutes intervals, ranging from five to eight series, with two minutes breaks (table 2). The participants in the ECC-group performed ECC on the Cyclus2 Eccentric Trainer (RBM elektronik-automation GmbH, Leipzig, Germany), while those in the LCC-group used a simpler ergometer cycle (Body Bike Classic, BODY BIKE international a/s, Frederikshavn, Denmark). The seat on the ECC was set approximately 2 cm lower than regular seat height. The participants aimed at cycling at a cadence of 40 RPM through watching the display on the eccentric ergometer, or following a metronome (LCC-group).

The Borg Category-Ratio scale (CR10 scale) (Borg, 1998) was used to target intensity, whereas the participants rated exertion in the legs at the end of each interval (attachment 4). The participants were asked to perform ECC or LCC at an intensity starting at 4 (moderate to strong) in the first sessions, and increasing to 7-8 (very strong) in the last sessions. The Borg CR10 scale is considered both valid and reliable at measuring perceived exertion or pain (Noble et al., 1983; Borg, 1982). Additionally, feeling in the legs were rated from 1 (very,

very light) to 9 (very, very heavy), after the warm-up, as well as after completing the ECC or LCC (attachment 2).

Aerobic intervals

After the ECC or LCC, the training session continued with a 10-minute warm-up in order to increase the HR sufficiently before the aerobe intervals. The ECC-group were encouraged to do some short sprints with gradual increase in speed, since they were likely to have been working at a lower HR than those in the LCC-group. During the aerobic intervals most participants (n=18; ECC-group n=11, LCC-group n=7) used their own bike on CompuTrainers (RacerMate Inc, Seattle, Washington, USA) with cadence and Watt registration. At the first week 12 participants used the CompuTrainer; however, several participants followed after some sessions. The rest completed the aerobe intervals on the Body Bike Classic. The protocol for the aerobe intervals was the same for both the ECC- and the LCC-group (table 2). They trained intervals of four to 15 minutes, repeated in four to five series, with two minutes breaks. The intervals in the first sessions were to be performed at 83-87 percent of HR_{max} or 15-16 on the Borg scale, with the intensity increasing over the weeks reaching 93-98 percent of HR_{max} or 17-18 on the Borg scale in the last five sessions. The duration of the intervals decreased corresponding to the increase in intensity.

Measures of HR, Borg scale, and Watt were taken for each interval during the session. Additionally, session RPE was measured for the whole session after the 15 minutes of cool-down (attachment 5). The method is suggested to be useful in detecting overtraining or undertraining, as well as predicting exercise intensity (Haile, Goss, & Robertson, 2013). Session RPE is considered reliable and valid in monitoring total exercise intensity of a session (Foster et al, 2001; Herman, Foster, & Maher, 2006). At the end of the session, each participant received a protein bar (*Proteinfabrikken*, big100 bar, 29g protein) in order to provide sustainable intake of proteins.

Table 2: Training protocol week 2-10.

Week	ECC / LCC	Borgs CR10	Break (min)	Aerobic interval 1st session	Aerobe interval 2nd session	Borg scale
1	**Pre-testing**					
2	5x2 min	4	2	4x12 min (83-87% HR_{max})	4x15 min (83-87% HR_{max})	15-16
3	5x2 min	5	2	4x12 min (83-87% HR_{max})	4x15 min (83-87% HR_{max})	15-16
4	6x2 min	5	2	4x12 min (83-87% HR_{max})	4x15 min (83-87% HR_{max})	15-16
5	6x2 min	6	2	5x8 min (88-92% HR_{max})	4x10 min (88-92% HR_{max})	16
6	7x2 min	7	2	5x8 min (88-92% HR_{max})	4x10 min (88-92% HR_{max})	16-17
7	8x2 min	7	2	5x8 min (88-92% HR_{max})	4x10 min (88-92% HR_{max})	16-17
8	8x2 min	7-8	2	5x4 min (93-98% HR_{max})	5x6 min (93-98% HR_{max})	17
9	7x2 min	7-8	2	5x4 min (93-98% HR_{max})	5x6 min (93-98% HR_{max})	17-18
10	6x2 min	7-8	2	5x4 min (93-98% HR_{max})		17-18
11	**Post-testing**					

The table presents the training protocol during the intervention period. It shows the number of weeks, duration and repetitions of eccentric cycling- (ECC) and low cadence cycling- (LCC) intervals, targeted rating of Borg CR10 scale during the ECC or LCC, breaks, targeted intensity during aerobic intervals in maximum heart rate (HR_{max}) at the first and second training session of the week, as well as targeted rating of Borg scale during the aerobic intervals.

4.5 Statistical analysis

All values are presented as mean and standard deviation (SD), if not otherwise stated. Differences between the groups at pre- and post-test, and difference in relative change from pre- to post-test were analyzed with independent-samples t-tests. Levene's test for equality of variances were conducted for choosing the correct *p*-value in the independent-samples t-tests. Changes from pre- to post-test within each group were analyzed with paired-samples t-tests. The association between variables were investigated using Pearson (*r*) or Spearman (*rho*) correlation coefficients. Missing values for analyses were treated with "*exclude cases analysis by analysis*" or "*exclude cases pairwise*" in SPSS, meaning that cases were excluded only when data were missing for the specific analysis. Preliminary analyses (scatterplots) were performed to identify possible outliers and inspect the distribution of data points. When the data points were not arranged evenly in a linear pattern, Spearman correlation coefficients were used.

All tests were done with a 95 percent confidence interval (*CI*). The level of significance was set to $p \leq 0.05$. Analysis were performed in IBM SPSS Statistics (version 23) and Microsoft

Excel for Mac (version 15.20 (160315)). The y-axis in figure 5 to 14 does not start at 0. The size of the correlation coefficients was interpreted in the following way: 0.0-0.3=negligible correlation, 0.3-0.5=low correlation, 0.5-0.7=moderate correlation, 0.7-0.9=high correlation, and 0.9-1.0=very high correlation (Mukaka, 2012).

Cohens'd effects sizes were calculated for cases of significant findings through equations on the following webpage: http://www.psychometrica.de/effect_size.html#dep. For significant differences in relative change from pre- to post-test between the groups, the Cohen's d effect size was calculated using values for means, SD, and sample size through the formula under subheading two at the webpage. For significant changes within a group, Cohen's d effect size was calculated using the t-value, number of cases, and the correlation between the values through the formula for dependent tests under subheading four at the webpage. The guidelines proposed by Cohen, 1988 were used in interpreting the effect size; 0.2=small/merely, 0.5=medium/subtle, and 0.8=large/obvious (Fritz, Morris, & Richler, 2012). The effect size is presented as the magnitude of the difference or change, while the direction of the difference or change is explained in the text.

The data from one participant (ECC-group) was removed from the analysis of the dynamometer and the 20 minute all-out, and the data from three participants (two from ECC-group, one from LCC-group) were removed from analysis of the VO_{2max}, 20 minute all-out, and lactate profile tests. Removing the data from the tests were due to illness during test, not completing test, or lack of motivation during test, limiting the trust of the data's validity. The participants were eliminated from calculations of mean (SD) in the same tests, in order to not affect pre- to post-test differences.

4.6 Ethical considerations

The study was approved by the Southern Norway regional division of the National Committees for Research Ethics. The ethical principles of the Declaration of Helsinki were followed. All participants read, understood and signed an informed consent form (attachment 6). The results of the study were anonymized during handling and publishing of the data. All data gathered in the study will be deleted by 2022.

5.0 Results

The results of the study are presented in table 3 and 4, as well as in text and figures. Analyses of differences between the groups at pre-test show a significantly lower mean $[la^-]_b$ during 20 minutes all-out in the LCC-group, mean difference=2.09 (*95% CI*=0.47-3.71) (*p*=0.015). For all other variables there were no significant differences between the groups at pre-test, including the variables in table 1. Body mass index (BMI) did not change in either of the groups during the intervention, consequently, there was no significant difference in relative change in BMI from pre- to post-test between the groups.

Table 3: **Pre-test and post-test values for the ECC-group and the LCC-group, means and standard deviations (SD).**

	Pre ECC mean (SD)	**Post ECC** mean (SD)	**Pre LCC** mean (SD)	**Post LCC** mean (SD)
BMI	23.5 (2.5)	23.4 (2.1)	23.1 (1.9)	23.2 (1.8)
Peak torque				
CON60° (Nm)	221 (37)	206 (40)	229 (33)	219 (31)
CON180° (Nm)	145 (26)	145 (27)	151 (23)	156 (23)
ISO60° (Nm)	241 (43)	255 (36)	263 (38)	256 (34)
ISO90° (Nm)	241 (37)	238 (46)	251 (48)	249 (45)
Muscle thickness				
Mean m. quad (cm)	2.5 (0.2)	2.6 (0.2)	2.4 (0.2)	2.3 (0.3)
Mean m. biceps (cm)	3.3 (0.4)	3.4 (0.6)	3.2 (0.8)	3.2 (0.7)
Lactate profile				
%VO_{2max} at LT	74.7 (6.2)	76.7 (3.8)	72.8 (9.8)	73.3 (7.9)
$[la^-]_b$ (mmol/L)				
125W	1.7 (0.8)	1.5 (0.6)	1.9 (0.7)	2.0 (0.8)
175W	2.2 (1.4)	1.7 (0.9)	2.4 (1.5)	2.0 (1.0)
225W	2.8 (1.2)	2.5 (0.7)	2.8 (1.4)	2.3 (1.0)

The table shows results for body mass index (BMI) and selected variables from the dynamometer, ultrasound, blood lactate profile, and cycling efficiency/economy tests. Results are presented at baseline (pre) and 10 weeks after (post) for the eccentric cycling group (ECC) and the low cadence cycling group (LCC). The table only shows variables not presented in the figures. CON=concentric; ISO=isometric; Nm=newton meter; m. quad=m. quadriceps femoris; m. biceps=m. biceps femoris; VO_{2max}=maximum oxygen consumption; LT=lactate threshold; $[la^-]_b$=blood lactate concentration; W=Watt.

Table 4: Within group changes, means and standard deviations (SD), and relative changes between groups.

	ECC % change mean (SD)	**LCC % change** mean (SD)	**% difference** (*p*-value)
BMI	-0.2 (1.8)	0.6 (1.9)	0.334
Peak torque			
EC (Nm)	10.9 (6.4)*	1.6 (6.2)	0.007*
CON60° (Nm)	-6.8 (8.7)*	-39 (6.3)	0.406
CON180° (Nm)	-0.3 (6.2)	3.2 (4.7)	0.167
ISO60° (Nm)	8.2 (18.3)	-2.4 (9.4)	0.118
ISO90° (Nm)	-1.3 (11.6)	-0.6 (5.9)	0.851
Muscle thickness			
Mean m. quad (cm)	2.2 (3.0)*	-0.9 (6.9)	0.172
Mean m. biceps (cm)	2.4 (8.5)	1.8 (8.8)	0.875
VO_{2max}-test			
VO_{2max} *(mL/min/kg)*	6.0 (9.0)*	3.8 (4.5)*	0.495
W_{max}	3.2 (3.6)*	5.9 (4.4)*	0.156
Lactate profile			
Power output (W) at LT	6.5 (9.8)*	10.0 (15.0)*	0.539
VO_2 *(mL) at LT*	9.0 (10.0)*	7.1 (7.5)*	0.641
$\%VO_{2max}$ *at LT*	3.3 (9.9)	1.2 (7.1)	0.587
Cycling economy			
125W: VO_2 *(mL)*	3.8 (10.75)	-0.4 (4.0)	0.282
125W: $[la^-]_b$ *(mmol/L)*	-5.9 (25.1)	7.3 (13.3)	0.191
175W: VO_2 *(mL)*	1.2 (7.04)	-0.6 (2.3)	0.459
175W: $[la^-]_b$ *(mmol/L)*	-17.3 (23.2)	-7.0 (30.4)	0.430
225W: VO_2 *(mL)*	2.3 (4.91)	1.1 (4.1)	0.616
225W: $[la^-]_b$ *(mmol/L)*	-7.8 (18.6)	-10.5 (22.2)	0.792
20 min all-out			
Mean power output (W)	3.1 (4.7)	7.5 (6.5)*	0.112
Mean $[la^-]_b$ *(mmol/L)*	-5.9 (16.6)	22.6 (35.5)	0.044*

The table shows results for body mass index (BMI) and selected variables from the dynamometer, ultrasound, VO_{2max}, blood lactate profile, cycling efficiency/economy, and 20 minutes all-out tests. Results are presented as percentage change from pre- to post-test for the eccentric cycling group (ECC) and the low cadence cycling group (LCC), as well as *p*-value for relative difference in change between the groups. EC=eccentric; CON=concentric; ISO=isometric; Nm=newton meter; m. quad=m. quadriceps femoris; m. biceps=m. biceps femoris; VO_{2max}=maximum oxygen consumption; W_{max}=maximum aerobic power output; W=Watt; VO_2=oxygen consumption; LT=lactate threshold; $[la^-]_b$=blood lactate concentration. *=statistical significance $p \leq 0.05$.

5.1 Strength development and muscle thickness

Significant differences in relative change in peak torque from pre- to post-test between the groups were found for eccentric knee extension, whereas the ECC-group (p=0.003) increased significantly more than the LCC-group (table 4), mean difference=9.2 (*95% CI*=2.94-15.55) (p=0.007). Effect size=1.475, large/obvious. Between pre- and post-test the ECC-group decreased significantly in concentric knee extension peak torque at 60°/second (p=0.023). Effect size=0.369, small/merely (attachment 7, figure 13). Additionally, the LCC-group reduced peak torque at 60°/second in concentric knee extension; however, the change was only close to significant (*p*=0.060). There were no changes in peak torque in concentric knee extension at 180°/second or isometric knee extension at 60° or 90° in any of the groups.

There was a negligible correlation between peak torque in eccentric knee extension and mean power output (Watt) during 20 minutes all-out (all participants: *rho*=-0.22, *p*=0.459, ECC-group: *rho*= 0.30, *p*=0.624, LCC-group: *rho*=-0.05, *p*=0.898). Between eccentric peak torque and determinants of performance, correlations were negligible or low, when studying all participants. However, for the ECC-group, moderate negative correlations were found between eccentric peak torque and $[la^-]_b$ at 175W and VO_2 at 225W during the blood lactate profile test (*rho*=-0.70, *p*=0.188 and *rho*=-0.66, *p*=0.156 respectively).

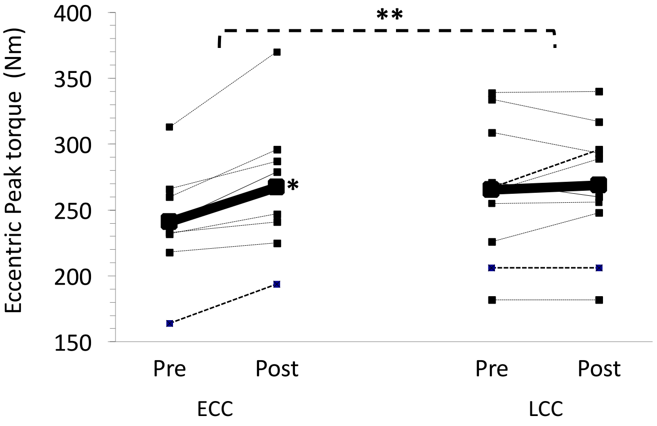

Figure 5: Peak torque (Nm) in eccentric knee extension at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=8) and the low cadence cycling-group (LCC, n=10). (ECC-group: 241-267Nm, LCC-group: 265-269Nm). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group (*p*≤0.05). **=significant difference in change pre- to post-test between the groups (*p*≤0.05).

No significant differences in relative change of muscle thickness of m. quadriceps femoris or m. biceps femoris were found from pre- to post-test between the groups (*p*=0.172 and *p*=0.875 respectively). Between pre- and post-test, mean muscle thickness of m. quadriceps femoris increased significantly in the ECC-group (*p*=0.024). Effect size=0.205, small/merely (figure 14).

There was a negligible correlation between muscle thickness of m. quadriceps femoris and m. biceps femoris and eccentric peak torque (*r*=0.06, *p*=0.823 and -0.01, *p*=0.959 respectively). Also, in the ECC- and LCC-group separately, the correlations between muscle thickness of m. quadriceps femoris and eccentric peak torque were negligible (*r*=0.28, *p*=0.497 and *rho*=-0.18 and *p*=0.626 respectively). The correlation between muscle thickness of m. quadriceps femoris and eccentric peak torque in the ECC-group was affected by one outlier. When the analyses were performed excluding this outlier, there was a significant high positive correlation (*r*=0.76, *p*=0.045). All correlations were negligible or low between muscle thickness of m. quadriceps femoris or m. biceps femoris and determinants of performance or mean power output (Watt) during 20 minutes all-out.

5.2 Maximum oxygen consumption and maximum aerobic power output

No significant differences in relative change of body mass-adjusted VO_{2max} (mL/min/kg) were found from pre- to post-test between the groups (*p*=0.495). Between pre- and post-test VO_{2max} (mL/min/kg) increased significantly in both the ECC-group (*p*=0.042), and the LCC-group (*p*=0.030). Effect size=0.249, small/merely and 0.261, small/merely respectively (figure 6).

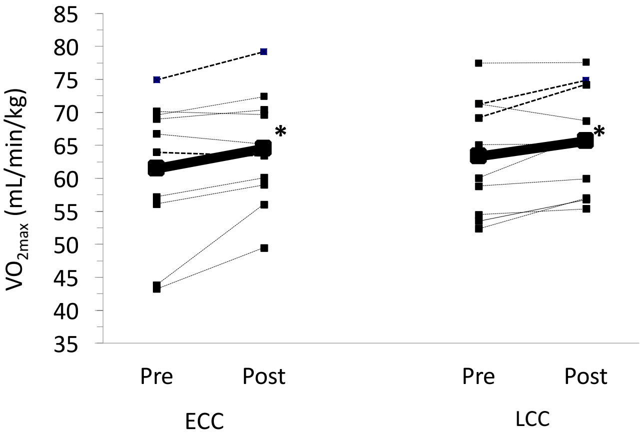

Figure 6: Maximum oxygen consumption (VO_{2max}) (mL/min/kg) at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=10) and the low cadence cycling-group (LCC, n=10). (ECC-group: 61.5-64.5mL/min/kg, LCC-group 63.3-65.6mL/min/kg). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group (*p*≤0.05).

No significant differences in relative change of W_{max} were found from pre- to post-test between the groups (*p*=0.156). Between pre- and post-test W_{max} increased significantly in both the ECC-group (*p*=0.024) and the LCC-group (*p*=0.002). Effect size=0.258, small/merely and 0.612, medium/subtle respectively (figure 7).

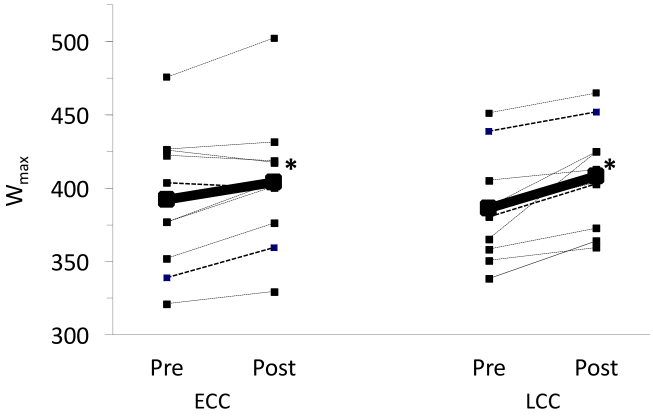

Figure 7: Maximum aerobic power output (W_{max}) at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=10) and the low cadence cycling-group (LCC, n=10). (ECC-group: 392-404W, LCC-group 386-408W). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group ($p \leq 0.05$).

5.3 Lactate threshold

Percentage of VO_{2max} at 4 mmol/L:

No significant differences in relative change of the percentage of VO_{2max} at 4 mmol/L were found from pre- to post-test between the groups (*p*=0.587). Between pre- and post-test, the percentage of VO_{2max} at 4 mmol/L did not change in any of the groups (attachment 7, figure 15).

Mean power output at 4 mmol/L:

No significant differences in relative change of mean power output (Watt) at 4 mmol/L were found from pre- to post-test between the groups (*p*=0.539). Between pre- and post-test mean power output at 4 mmol/L increased significantly in both the ECC-group (*p*=0.037) and the LCC-group (*p*=0.042). Effect size=0.25, small/merely and 0.334, small/merely respectively (figure 8).

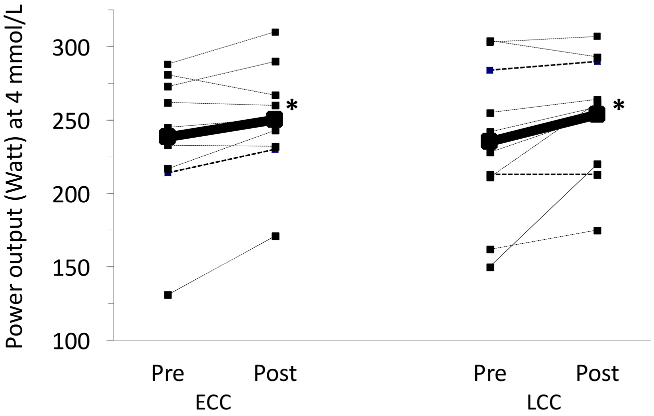

Figure 8: Power output (Watt) at 4 mmol/L at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=10) and the low cadence cycling-group (LCC, n=10). (ECC-group: 238-250W, LCC-group: 235-254W). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group (*p*≤0.05).

VO_2 at 4 mmol/L:

No significant differences in relative change of mean VO_2 at 4 mmol/L were found from pre- to post-test between the groups (*p*=0.641). Between pre- and post-test mean VO_2 at 4 mmol/L increased significantly in both the ECC-group (*p*=0.002) and the LCC-group (*p*=0.015). Effect size=0.355, small/merely and 0.348, small/merely respectively (figure 9).

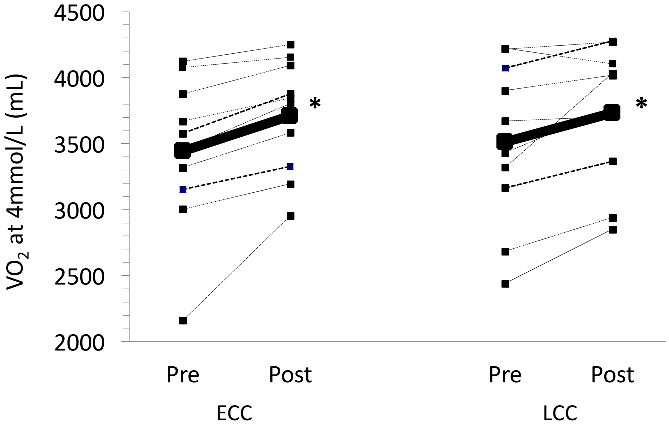

Figure 9: Oxygen consumption (VO_2) (mL) at 4 mmol/L at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=10) and the low cadence cycling-group (LCC, n=10). (ECC-group: 3442-3709mL, LCC-group: 3513-3734mL). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group (p≤0.05).

5.4 Cycling economy

VO_2 and $[La^-]_b$ at 125W, 175W, and 225W:

No significant differences in relative change of VO_2 or $[La^-]_b$ at 125W, 175W, or 225W were found from pre- to post-test between the groups. Nor were there any significant changes within the groups between pre- and post-test for VO_2 and $[La^-]_b$ at 125W, 175W, or 225W (figure 10a & b and attachment 7, figure 16a & b).

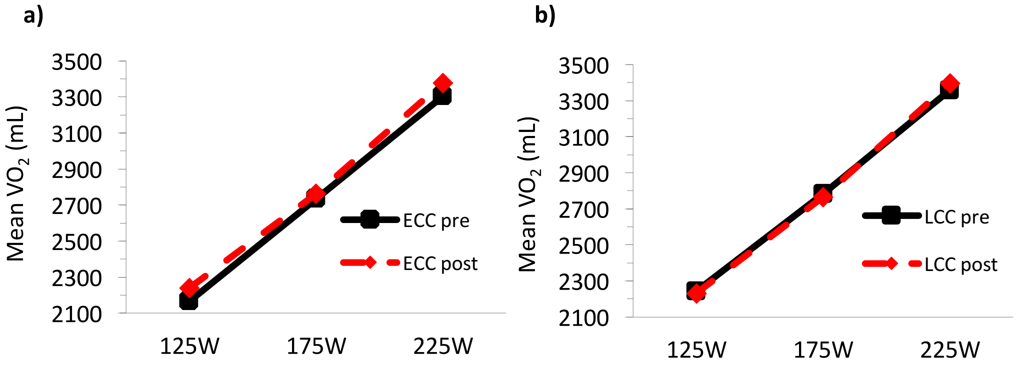

Figure 10a & b: Mean oxygen consumption (VO_2) (mL) at 125W, 175W, and 225W during the blood lactate profile test. Black solid line=at pre-test. Red dotted line=at post-test. **a**=eccentric cycling group (ECC), n=10 (125W), 10 (175W), 9 (225W). **b**=low cadence cycling group (LCC), n=9 (125W), 9 (175W), 7 (225W). (SD ECC-group: 125W: 139-163mL, 175W: 115-154mL, 225W: 159-180mL, SD LCC-group: 141-106mL, 101-113mL, 66-142mL).

5.5 Cycling performance

Mean power output during 20 minutes all-out:

No significant differences in relative change of mean power output (Watt) during 20 minutes all-out were found from pre- to post-test between the groups (p=0.112). Mean power output increased significantly from pre- to post-test in the LCC-group (p=0.003). Effect size=0.438, small/merely (figure 11).

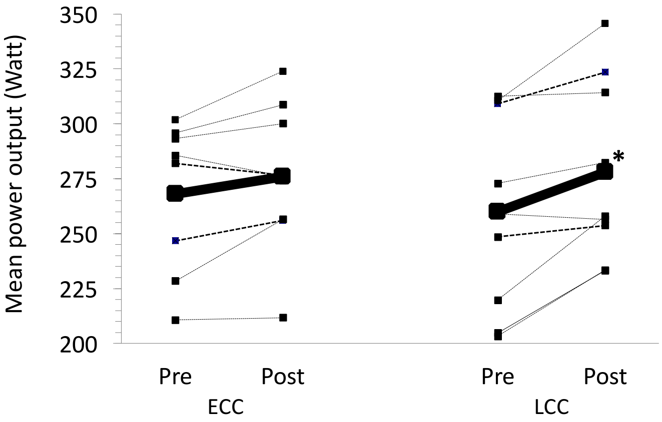

Figure 11: Mean power output (Watt) during 20 minutes all-out at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=9) and the low cadence cycling-group (LCC, n=10). (ECC-group: 268-276W, LCC-group: 260-278W). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group ($p \leq 0.05$).

Mean [La$^-$]$_b$ during 20 minutes all-out:

The relative change of mean [La$^-$]$_b$ during 20 minutes all-out from pre- to post-test between the groups were significantly different, mean difference=-28.6, (*95% CI*=-56.29 – -0.89) (*p*=0.044). Effect size=0.759, medium/subtle. The difference in mean [La$^-$]$_b$ was due to a non-significant decrease in the ECC-group (*p*=0.206) and a non-significant increase in the LCC-group (*p*=0.145) between pre- and post-test (figure 12).

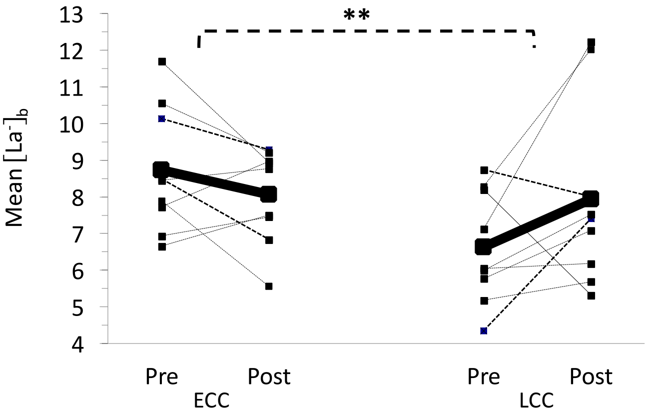

Figure 12: Mean blood lactate concentration [La$^-$]$_b$ during 20 minutes all-out at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=9) and the low cadence cycling-group (LCC, n=9). (ECC-group: 8.73-8.06 mmol/L, LCC-group: 6.63-7.94 mmol/L). The figure shows mean (thick line) and each individual data point (dotted lines). **=significant difference in change pre- to post-test between the groups ($p \leq 0.05$).

6.0 Discussion

The current study hypothesized that 1) The ECC-group would have a greater development of eccentric strength and muscle thickness than the LCC-group; 2) The ECC-group would have better effects on cycling performance (20 minutes all-out), cycling economy, and power output at the LT than the LCC-group, and; 3) VO_{2max} and W_{max} would increase to the same degree in both groups.

In accordance with hypothesis 1, the ECC-group increased significantly more in eccentric muscle strength than the LCC-group. Additionally, the ECC-group had a significant increase in muscle thickness of the quadriceps muscles; however, the change was not significantly higher than in the LCC-group. Thus, hypothesis 1 was only partly supported. The main finding of the current study was that ECC did not result in any positive effects on cycling performance or determinants of cycling performance compared with LCC; and thus hypothesis 2 was rejected. Finally, our findings supported hypothesis 3. Both VO_{2max} and W_{max} were significantly increased from pre- to post-test in both groups, and there was no significant difference in the change between the groups.

Other significant findings of the current study were that the LCC-group improved cycling performance and mean $[la^-]_b$ during 20 minutes all-out, and the improvement in mean $[la^-]_b$ was significantly higher than in the ECC-group. Also, the ECC-group had a significant reduction in concentric muscle strength at 60°/second. Finally, power output and VO_2 at the LT were improved from pre- to post-test to the same degree in both groups. While cycling economy and percentage of VO_{2max} at the LT on the other hand, did not change in any of the groups.

This chapter discusses the effect of concurrent ECC and endurance training found in the current study related to strength development and muscle thickness, VO_{2max} and W_{max}, LT, cycling economy, cycling performance, and the health perspective. Finally, the chapter ends with a discussion of the methodology of the study.

6.1 Strength development and muscle thickness

The finding of improved eccentric strength in the ECC-group are in accordance with the findings in the review of Isner-Horobeti and colleagues (2013). They state that eccentric strength training seems to affect eccentric muscle strength more than concentric muscle strength. In fact, the effect of strength training seems to be contraction specific (Higbie, Cureton, & Warren, 1996). Nevertheless, LaStayo and co-authors (2011, 2010), found improved concentric peak torque after 12 weeks of ECC. However, the participants were cancer survivors with a perception of moderate muscle weakness and fatigue. Thus, the difference in physical fitness level of the participants in the latter studies and the current study, might partly explain the divergent findings regarding concentric peak torque.

The lack of significant changes in isometric leg strength after ECC, is supported by one study (Gross et al., 2010); however, contradicted by other studies (Mueller et al., 2009; LaStayo et al., 2003a; LaStayo et al., 2000; LaStayo et al., 1999). Again, this might be partly explained by the physical fitness level of the individuals. The participants in the current study were trained individuals, and the participants in the study supporting the current findings (Gross et al., 2010) were athletes, while the participants in the studies showing improvements in isometric leg strength were either healthy individuals (LaStayo et al., 2000; LaStayo et al., 1999) or older adults (Mueller et al., 2009, LaStayo et al., 2003a).

Additionally, the disagreeing literature may be related to the characteristics of the training interventions, such as different cadence applied in different studies. It is likely that the diverse cadence used in studies will cause different muscle adaptations. Previous studies show that ECC-movements are better tolerated when performed at low cadence (Chapman, Newton, & Sacco, 2006), and some studies have used velocities as low as 15 RPM (Laroche et al., 2013). In the current study the participants trained at 40 RPM, while other studies have used cadence ranging from 20-80 RPM (Elmer et al., 2013; Gerber et al., 2007a, 2007b; Dufour et al., 2004; LaStayo et al., 2000; LaStayo et al., 1999).

There were no relative differences between the groups from pre- to post-test for either m. biceps femoris- or m. quadriceps femoris muscle thickness. However, muscle thickness of m. quadriceps femoris increased significantly from pre- to post-test in the ECC-group. The ultrasound examination method does not measure CSA of muscles or muscle fibers; however, the muscle thickness measured with ultrasound is associated with hypertrophy (Reeves et al., 2004). Other studies have also found hypertrophy after ECC (Leong et al., 2014; LaStayo et al., 2011; Gross et al., 2010; Mueller et al., 2009; Marcus et al., 2008; Gerber et al., 2007a; LaStayo et al., 2003a; LaStayo et al., 2000).

The improvements in both eccentric muscle strength and muscle thickness of the quadriceps muscles in the ECC-group, propose that the strength gain was related to hypertrophy (Isner-Horobeti et al., 2013; Kraemer & Ratamess, 2004). There was no correlation between muscle thickness of m. quadriceps femoris and eccentric peak torque in the ECC-group; however, the correlation coefficient was affected by one outlier. When the analyses were performed excluding this outlier the correlation was high, meaning that improved m. quadriceps femoris muscle thickness was associated with improved eccentric strength of the quadriceps muscles. Since the ECC-group increased significantly more in eccentric muscle strength, but not muscle thickness compared with the LCC-group, the strength gain was likely also related to neuromuscular factors (Kraemer & Ratamess, 2004). Neither of the groups changes in net body weight during the intervention, suggesting that the increased muscle thickness in the ECC-group occurred with a concurrent decrease in fat-mass.

Concurrent endurance and strength training might have attenuated effects on the development of muscle hypertrophy (Putman et al., 2004) and strength gains (Izquierdo et al., 2005) compared to strength training alone. This might to some degree explain the reduction of concentric strength in the ECC-group. Additionally, we might assume that the eccentric strength and muscle thickness development would be greater after ECC performed alone.

The aim of the ECC was to improve muscle strength. Strength training, may among other effects, cause improved neural function and enhanced tendon stiffness, which may increase the rate of force development (RFD) (Aagaard & Andersen, 2010). High RFD in the hip-flexor muscles likely increases pedaling efficacy and possibly improves cycling performance (Hansen et al., 2012). It was hypothesized that the ECC-group would develop strength gains and that these gains would cause improved determinants of cycling performance.

In the current study, improved eccentric muscle strength and increased muscle thickness of m. quadriceps femoris, were not correlated with cycling performance measured as mean power output during 20 minutes all-out. However, in the ECC-group, there were moderate negative correlations between eccentric peak torque and measures of cycling economy, which have been related to cycling performance (Hopker et al., 2009; Lucía et al., 2002; Horowitz et al, 1994).

The conflicting literature on the effect of concurrent strength and endurance training on cycling performance (Rønnestad et al., 2015; Psilander et al., 2015; Rønnestad et al., 2011;

Aagaard et al, 2011; Rønnestad et al., 2010a; Rønnestad et al., 2010b; Levin et al., 2009; Jackson et al., 2007; Millet et al., 2002; Bishop et al., 1999) may have several explanations. These are related to the characteristics of the interventions applied and the individuals participating in the interventions. Firstly, different strength training methods are likely to cause different muscle adaptations (Raastad et al., 2010). With training methods in strength training we are referring to the volume of training, load, number of repetitions, number of series, length of breaks, type of exercises, muscles involved, and type of muscle work.

Eccentric muscle work cause muscle damage (Isner-Horobeti et al., 2013; Cleak & Eston, 1992). Biopsies from m. vastus lateralis immediately after ECC revealed disorganization of sarcomeres (Manfredi, Fielding, & O'Reilly, 1991). However, the "repeated bout effect" after repetitive eccentric muscle work, causes the muscles to adapt to the resistance, triggering less muscle damage and stops the decrease in muscle performance (Paddon-Jones et al., 2000). The training volume in the current study of 17 training sessions over 10 weeks, is likely to have caused the repeated bout effect. However, it has been claimed that a longer tapering period from the last training session until testing is necessary after ECC to show the true effects (Leong et al., 2014).

Secondly, the order of the training sessions is important when training concurrent strength and endurance training. For trained individuals, the type of capacity (strength or endurance) that is the main goal to increase should be trained first if both are trained on the same day (Chtara et al., 2005; Nelson, Arnall, & Loy, 1990). Also, for best outcome, the restitution period between training the two capacity types should be as long as possible (Raastad et al., 2010). In our study, ECC was performed prior to endurance training in the same training session. However, the break between training the two capacity types was only 10 minutes.

Thirdly, the different methods of testing used when evaluating the effect of interventions may cause conflicting literature. Testing strength through a 1 RM test versus isometric or isokinetic tests, have shown to give somewhat different results (Raastad et al., 2010). Finally, the characteristics of the participants should be considered when comparing literature. It is likely that an untrained individual will respond quicker and to a higher degree to a training stimuli than a well-trained individual (Henriksson & Sundberg, 2008; Ahtiainen, Pakarinen, & Alen, 2003). Additionally, we should keep in mind that genetic, sociological, and motivational factors may affect how the individuals respond to a training program (Joyner & Coyle, 2008).

6.2 Maximum oxygen consumption and maximum aerobic power output

The significant increase in body mass-adjusted VO_{2max} from pre- to post-test in both the ECC-group and the LCC-group was expected. Only the ECC-group had significant improvements in muscle strength, hence, the improved VO_{2max} might not be a consequence of increased muscle strength. This is in accordance with other studies, showing neither negative nor positive effects of concurrent strength and endurance training for cyclists, compared with endurance training performed alone (Rønnestad et al., 2015; Rønnestad et al., 2011; Aagaard et al., 2011; Sunde et al., 2010; Rønnestad et al., 2010a; Levin et al., 2009). Since both groups trained the same aerobic intervals throughout the intervention period, it was likely that they both would have an increase in VO_{2max} independent from any potential increase in muscle strength.

In addition, the intervention was applied in the winter season after a period when the cyclists' training volume had been low. The increased training volume caused by the intervention is likely to cause increased VO_{2max}. Though most studies have shown no effect of concurrent training on VO_{2max}, few of these investigated the relation on long term. Additionally, in some of the studies the increase in VO_{2max} tends to level out in the last part of the intervention period when comparing with only endurance training (Bell, Peterson, & Wessel, 1991; Nelson et al.,1990). Hence, concurrent training may have a negative effect on VO_{2max} if trained over longer periods; however, this is still not known (Raastad et al., 2010).

Both groups increased significantly in W_{max}; however, only the ECC-group had significant improvements in muscle strength. Therefore, the improved W_{max}, might not be a consequence of increased muscle strength. W_{max} has been related to VO_{2max}, cycling economy, anaerobic capacity, and neuromuscular characteristics (Jones & Carter, 2000). Hence, the improvements in W_{max} seen in both groups in the current study may be related to the endurance training and the improvement also seen in VO_{2max}, and possible improvements in anaerobic capacity and neuromuscular characteristics not covered in this thesis.

6.3 Lactate threshold

Both groups improved significantly in power output (Watt) and VO_2 (mL) at the LT, though strength improvements were only seen in the ECC-group. Therefore, the improvements in the LT were likely not caused by enhanced muscle strength. Power output and VO_2 at the LT seems to be depended on VO_{2max} and work economy (Rønnestad & Mujika, 2014; Joyner &

Coyle, 2008). Hence, the improvements in power output and VO_2 at the LT in both groups, might be associated with improvements also found for VO_{2max}.

The improvements in power output at the LT are inconsistent with some studies finding no changes after concurrent strength and endurance training in cyclists (Aagaard et al., 2011; Sunde et al., 2010; Bishop et al., 1999), while in accordance with other studies indicating positive effect on power output at the LT in sedentary men (McCarthy, Agre, & Graf, 1995) and in well-trained cyclists (Rønnestad et al., 2015; Rønnestad et al., 2010a; Rønnestad et al., 2010b). The studies showing no change differ from the other studies in that they were implemented in the preparatory period; however, the current study was also implemented in the preparatory period, and it still showed improvements.

Power output at a set $[La^-]_b$ obtained during a continuous incremental exercise test is a strong predictor of endurance performance for cyclists (Coyle et al., 1991). Hence, the improved power output at 4 mmol/L in the current study might be associated with improved cycling performance. It seems as the LT measured as power output or VO_2 has a stronger relation with endurance performance than percentage of VO_{2max} at the LT (Støren et al., 2013). The percentage of VO_{2max} at the LT is independent from VO_{2max} and work economy (Støren, Ulevåg, & Larsen, 2013), hence it is not surprising that both groups had elevated VO_{2max}, without improvements in percentage of VO_{2max} at the LT. This is in agreement with other studies, finding no significant changes in percentage of VO_{2max} at the LT after concurrent strength and endurance training (Rønnestad et al., 2015; Sunde et al, 2010).

6.4 Cycling economy

Increased cycling economy would be portrayed as lower VO_2 at the same power output (Watt) (Abbiss & Laursen, 2005). No significant changes in cycling economy was found in any of the groups. In agreement with our findings, other studies on well-trained cyclists, have found no significant change in cycling economy after concurrent strength and endurance training (Rønnestad et al., 2010b; Aagaard et al., 2007). On the contrary, other studies have found increased cycling economy or cycling efficiency after strength training performed alone (Barrett-O'Keefe et al., 2012; Loveless et al., 2005), or strength training added to usual endurance training (Louis et al., 2012; Sunde et al., 2010). The studies were done with both untrained men (Loveless et al., 2005), trained individuals (Barrett-O'Keefe et al., 2012), and competitive cyclists (Sunde et al., 2010). Moreover, concurrent heavy strength and endurance training has been recommended to improve cycling economy (Rønnestad & Mujika, 2014). It might seem as improved cycling efficiency/economy is dependent on the cyclists' performance level (Vikmoen, 2015), whereas those who experience the most improvements are of lower performance level (Barrett-O'Keefe et al., 2012; Louis et al., 2012; Sunde et al., 2010; Loveless et al., 2005).

Another theory is based on an invert relationship between VO_{2max} and efficiency/economy found in professional cyclists and runners (Lucía et al., 2002; Pate, Macera, & Bailey, 1992). Though the participants in the current study were not athletes, the VO_{2max} and efficiency/economy relationship seen in the two latter studies, may indicate that the significant improvements in VO_{2max} in both groups may have inhibited improvements in cycling economy. This thesis did not investigate potential changes in muscle fiber type or pedaling technique shown to be related to cycling efficiency/economy. Finally, it has been suggested that cycling efficiency may be affected by body size; however, body size remained unchanged from pre- to post-test in both groups in the current study.

With improved cycling economy, we may expect a lower $[La^-]_b$ at the same power output. In the current study, no significant changes were found for $[La^-]_b$ at 125W, 175W, or 225W. These findings are supported by a study on concurrent strength and endurance training (Rønnestad et al., 2010b). Yet, the same study found significantly lower $[La^-]_b$ at 275W 12 and 25 weeks after pre-testing (Rønnestad et al., 2010b). Another study found reduced $[La^-]_b$ during the last hour of 180 minutes of cycling at 44 percent of W_{max}, after 12 weeks of concurrent heavy strength and endurance training (Rønnestad et al., 2011). The change was not significant; however, it was significantly different from the group who had done only endurance training. We were not able to do any analysis at the 275W stage due to the few participants reaching the LT at that stage. It seems that longer interventions might capture larger differences in $[La^-]_b$ at different power outputs during submaximal exercise. Also, it seems as concurrent training has more effect on $[La^-]_b$ at higher power outputs. However, more research is necessary to make any conclusions.

6.5 Cycling performance

Cycling performance measured as mean power output (Watt) during the 20 minutes all-out time trial increased significantly in the LCC-group. The relative difference between the groups were not significant. Performance in endurance sports are mainly determined by VO_{2max}, fraction utilization of VO_{2max}, and work efficiency/economy (Coleman, 2012; Joyner

& Coyle, 2008; Basset & Howley, 2000). Muscle strength on the other hand, has been shown to correlate poorly with time trial cycling performance (Støren et al., 2013).

With the improvements in VO_{2max}, W_{max}, and LT expressed as power output and VO_2, increased performance at 20 minutes all-out was not surprising. However, it was surprising that it only improved in the LCC-group. The LCC-group had a lower mean power output at pre-test than the ECC-group, though the difference was not significant. Still, it might explain to some degree the higher increase in mean power output in the LCC-group. Cycling economy did not change significantly in either group and cannot explain the improvements in performance in the LCC-group, or the absence of improvements in the ECC-group.

The lack of performance improvements in the ECC-group could be partly explained by an increase in body mass as a result of improved strength and hypertrophy (Raastad et al., 2010). An increase in lean mass without a simultaneous decrease in fat mass would cause an increased net body mass. For the cyclist this would mean more weight to carry, which may negatively influence cycling performance. However, this was not the case, since the ECC-group did not change net body mass during the intervention.

For mean $[La^-]_b$ during the 20 minutes all-out, the LCC-cycling group had a significantly lower mean than the ECC-group at pre-test. Additionally, there was a significant difference between the groups in relative change of mean $[La^-]_b$ from pre- to post-test. The difference was due to the ECC-group having a non-significant decrease, and the LCC-group having a non-significant increased. The small decrease in mean $[La^-]_b$ in the ECC-group, and no increase in mean power output, may be due the participants in the group not being able to work maximally during the 20-minutes all-out, perhaps due to overtraining.

The differences between the groups for mean power output and $[la^-]_b$, could be partly explained by the learning effect of having performed the 20 minutes all-out test before. After performing the test one time, the participants might have learned approximately what mean power output they could hold for 20 minutes, making it easier to work as close to the limit as possible the second time. This might have been avoided if the participants did not see which Watt they were working at when controlling the power output. However, if the learning effect played a role in the 20 minutes all-out test, we would expect this to happen in both groups. Nonetheless, most of the participants had performed the 20 minutes all-out test in an earlier study at HiL, suggesting that the difference in mean power output and $[la^-]_b$ were not due to the learning effect.

Whether the 20 minutes all-out test is a valid test for endurance performance can be questioned. Mean and peak power output have shown to change with the length of the time trial, hence mean power output during 20 minutes all-out might not be generalizable to time trials of other durations (Bentley et al., 2001). We can speculate in whether a 40 or 60 minutes time trial would have given us different results. Cycling competitions are usually of longer duration than 20 minutes; however, the 20 minutes all-out test is less time-consuming to perform. Nevertheless, the 20 minutes all-out time trial is likely valid for endurance performance during 20 minutes.

In contrast to our findings, improved cycling performance (mean power output) during 40 and 45 minutes time trials were seen after concurrent strength and endurance training in well-trained cyclists (Rønnestad et al., 2015; Aagaard et al., 2011; Rønnestad et al., 2010a). These studies implemented interventions lasting 25 and 16 weeks. Improved cycling performance has also been found in well-trained cyclists during five minutes all-out following 185 minutes of cycling (Rønnestad et al., 2011). The improvements were only seen in the group who had performed concurrent heavy strength training and endurance training for 12 weeks.

Another study, found improved performance during a 60 minutes time trial, after replacing a part of the endurance training with low loaded explosive strength training for nine weeks (Bastiaans et al., 2001). However, improved performance was also seen in the group who had performed endurance training only. It has been suggested that the intervention period of nine weeks might have been too short to give improvements in performance when adding low loaded explosive strength training (Rønnestad et al., 2010b). The intervention period in our study, was only one week longer than the latter study; however, the ECC and LCC was performed with high intensity.

Similar to the ECC-group in our study, no performance improvements (mean power output) was found during a 60 minutes time trail, after 12 weeks of concurrent strength and endurance training for endurance-trained women (Bishop et al., 1999). The conflicting findings with regards to concurrent strength and endurance training on performance, might be due to differences in the strength training methods, gender, as well as the duration of the time trials when testing endurance performance. In addition, performance may be affected by genetic, sociological, or motivational factors (Joyner & Coyle, 2008), not measured in the current study.

6.6 A health perspective

The current study was conducted with a performance perspective, investigating determinants of cycling performance. However, much of the research that have studied the effect of ECC have been performed within a health perspective. Strength and factors of aerobic fitness investigated in the current study are important determinants for health, both for older adults and for individuals with different disorders (Henriksson & Sundberg, 2008; Jansson, Stensvold, & Ulrik, 2008). Also, previous studies have found effect of ECC on other aspects related to health benefits. These aspects were not investigated in this study; however, we can speculate in whether adapting our intervention to a vulnerable population may have caused additional health benefits. As an addition to the performance perspective of the current thesis, this chapter discusses ECC as well as concurrent strength and endurance training in a health perspective.

Eccentric strength training may give higher strength gains than conventional strength training for older adults (Reeves et al., 2009). Eccentric muscle contractions are characterized by generating antigravity and braking movements (Gault & Willems, 2013). Thus, improved eccentric strength as found in the current study, is beneficial for maintaining independence and braking or avoiding falls (Gault & Willems, 2013). Strength training may increase the RFD (Aagaard & Andersen, 2010), important for correcting imbalance quickly and avoiding falls (Bassey, Fiatatone, & O'Neill, 1992). Additionally, heavy strength training has a positive effect on BMD (Raastad et al., 2010). The BMD declines with increased age or immobilization, and enhances the risk of fractures. Therefore, maintaining BMD is of great importance for vulnerable individuals and older adults.

In a study on individuals with Parkinson's disease, high intensity ECC caused improvements in bradykinesia, muscle force, gait speed, timed up-and-go, as well as quality of life (Dibble et al., 2009). The gait speed and timed up-and-go tests are important for testing functional mobility. Other studies on ECC with frail older adults, have found significant improvements for maximal isometric knee extension strength, eccentric muscle coordination, relative thigh lean mass (Mueller et al., 2009), muscle fiber CSA, timed up-and-go task, quadriceps isometric muscle strength, balance performance, stair descent time, and going from a high to a low fall risk (LaStayo et al., 2003a).

ECC may also be advantageously used in rehabilitation for patients with cardiorespiratory diseases, cancer survivors, or after surgery. Patients with chronic obstructive pulmonary disease (COPD), were able to cycle eccentrically at 69 percent of their W_{max} for 15 minutes without dyspnea (difficult or uncomfortable breathing) and with no need of additional oxygen (Rooyackers et al., 2003). The authors conclude that ECC, even at high intensities, is a safe and attractive method of training for patients suffering from severe COPD. For cancer survivors (breast, prostate, colorectal, and lymphoma), 12 weeks of ECC showed significant improvements for quadriceps muscle size, strength and power, as well as 6-minute walking distance and time to safely descend stairs (LaStayo et al., 2011). The authors suggest that the high-force and low perceived exertion during ECC makes it suitable for older individuals who are survivors of cancer.

After surgery such as anterior crucial ligament (ACL) reconstructions, thigh muscle atrophy is a major problem (Gerber et al., 2007a). A study on this population showed that the volume and peak CSA of the quadriceps and gluteus muscles increased significantly more in the ECC-group than in the standard rehabilitation group (Gerber et al., 2007a). Additionally, quadriceps strength and hopping distance increased more and the activity level decreased to a lesser extend in the ECC-group (Gerber et al., 2007b).

From a health perspective, concurrent strength and endurance training is recommended, to get the benefits from both training methods (Raastad et al., 2010). Research show that concurrent training is better for functional fitness than endurance or strength training performed alone (Wood et al., 2001; Ferketich, Kirby, & Alway, 1998). Concurrent endurance and strength trained by older adults have shown to cause a lower resting HR and rate-pressure product (HR_{max} x maximum systolic blood pressure), lower exercise diastolic blood pressure, increased muscular strength, and improved functional fitness through better flexibility, coordination, strength, agility, and cardiovascular endurance (Wood et al., 2001). Concurrent endurance and strength training is also recommended for individuals suffering from overweight or obesity, diabetes type 2, metabolic syndrome, or cardiovascular disease (Raastad et al., 2010). Hence, adapting our intervention of concurrent ECC and endurance training to a population of older adults or a population suffering from any of these conditions, may cause improvements in several health aspects.

In the current study, concurrent ECC and endurance training improved eccentric peak torque in knee extension, VO_{2max}, W_{max}, as well as power output and VO_2 at the LT. W_{max} and power output and VO_2 at the LT are variables tested in sports and not in studies on health. However, these variables are related to physical fitness level, which further is related to good health and reduced risk of developing a range of diseases (Henriksson & Sundberg, 2008). Thus, improvements in W_{max} and power output and VO_2 at the LT after concurrent ECC and endurance training might cause both improved endurance performance as well as enhanced health. VO_{2max} and muscle strength on the other hand, are frequently tested in health related studies. Enhanced physical fitness and muscle strength are important in increasing functional mobility and quality of life, as well as in prevention and rehabilitation of different disorders such as COPD, overweight or obesity, type 2 diabetes, metabolic syndrome, cardiovascular disease, or cancers (Henriksson & Sundberg, 2008; Jansson et al., 2008).

The significant improvement in eccentric quadriceps muscle strength after ECC found in the current study would be central in a population of vulnerable individuals. Firstly, the eccentric muscle strength is dominant in braking movements (Jindrich et al., 2006), and therefore might reduce the risk of falls and braking bones (Gault & Willems, 2013). Secondly, in addition to increasing the muscle mass and muscle strength, eccentric overload strength training may give site-specific increases in BMD (English, Loehr, & Lee, 2014). Thirdly, knee extensors seem to degenerate faster than elbow flexors (Nogueira et al., 2013), highlighting the importance of improving the quadriceps musculature of older adults. Finally, the gains in eccentric leg-strength has shown to increase physical fitness of older adults (Leszczak, Olson, & Stafford, 2013).

The improvements seen for the different variables in the current study have relevance in an endurance performance perspective as well as in a wider health perspective. When discussing the current findings in a health perspective, it is important to emphasize the fact that the participants in our study were healthy, trained individuals. Adapting a similar intervention to a population of older adults or vulnerable individuals suffering from any of the above mentioned conditions, is likely to cause greater improvements in muscle strength and physical fitness (Cowell et al., 2012; Guilheim et al., 2010; Roig et al., 2009; Henriksson & Sundberg, 2008; Ahtiainen et al., 2003).

6.7 Methodology

The main methodological limitation of this study was the lack of a control group doing only aerobic intervals and no ECC or LCC, and a control group performing only ECC and no endurance training. Such control groups would give us information about the difference of training only endurance training or ECC, versus concurrent ECC and endurance training. There were challenges during the recruitment period which did not allow for a larger samples size, and dividing the current participants into three groups would have underpowered the study. Nevertheless, the current sample size of 12 and 11 participants in each group is considered adequate compared with similar studies; however, it is considered low when determining the power of the results. Hence, the sample size should be kept in mind when interpreting the results.

We should also keep in mind that the timing of the intervention might have influenced the results to some degree since most of the participants are cyclists. The period before new year is usually a period of less training load for cyclists who start competing during the late spring, early summer. Hence, the period between January and March, is a period where the cyclists usually increase their training load, and gradually increase their endurance performance. It is expected that performance determinants will be enhanced during this period. Thus, all improvements may not only be related to the specifics of the intervention.

Additionally, though the current study is a non randomized controlled trial, we cannot see true causal relationships between the variables. Knowing this, we aimed at controlling for possible confounding factors, comparing the groups' baseline characteristics and comparing baseline values for all the variables used in the analysis. A strength of the study is that there were no significant differences between the groups in the baseline characteristics age, sex, weight, or heavy strength training on legs the last three months pre-intervention. Moreover, the only significant difference between the groups at pre-test was for the variable mean $[la^-]_b$ during the 20 minutes all-out test. For all other variables there were no significant differences between the groups at pre-test. Finally, a great strength is the high adherence (total 98%) to the training sessions during the intervention period.

All tests in this project were conducted in the physiological labs at HiL. Testing in a laboratory setting is criticized for lacking ecological validity since it does not exactly replicate the set-up of using a bike outside (Hopker & Jobson, 2012). Where it is possible, testing using ones' own equipment in a competition-like setting is optimal. However, this is not possible for tests that needs special equipment. Also external factors outside such as temperature, weather, and wind may affect the results of the tests. Therefore, most physiological tests are performed in a laboratory (Hopker & Jobson, 2012).

7.0 Conclusion

The current findings partly supported hypothesis 1. The ECC-group had significantly greater improvements in eccentric strength development than the LCC-group. Additionally, they had a significant increase in muscle thickness; however, it was not significantly higher than in the LCC-group. Hypothesis 2 on the other hand, was not supported by our findings. The ECC-group did not have better effects on cycling performance, cycling economy, or power output at the LT than the LCC-group. Finally, our findings support hypothesis 3. Both VO_{2max} and W_{max} increased in both groups, and there were no significant differences in the change between the groups.

ECC does not seem to give any positive effects on cycling performance or determinants of cycling performance compared with LCC. However, ECC seems to be more effective in improving eccentric muscle strength than LCC performed with the same perceived effort. The effect of ECC seems to be contraction specific. The findings in this thesis support other studies claiming that it is possible to improve muscle strength by increasing muscle thickness without causing greater body weight. Despite no increase in muscle strength, concurrent LCC and endurance training might improve cycling performance. Neither concurrent ECC nor LCC and endurance training improves the percentage of VO_{2max} at the LT or cycling economy. Finally, concurrent ECC or LCC and endurance training, does not seem to prevent improvements of the performance determinants VO_{2max}, W_{max}, or LT expressed as power output or VO_2. However, a control group doing only aerobic intervals would be necessary in order to conclude on this matter.

Based on the current study, concurrent ECC and endurance training seem to have an effect on eccentric strength development and some determinants of cycling performance. However, more research is needed to evaluate this effect, and to investigate what training volume, including intensity, cadence, duration, and frequency has the best effect for cyclists. Upcoming studies are encouraged to test cycling performance at longer time trials corresponding to the duration of competitions. Additionally, after reviewing the literature included in this thesis, it seems that strength gains from ECC as found in the current study, may be beneficial for older adults and vulnerable individuals. It would be interesting to further investigate the effect of ECC on strength development and functional fitness in a health perspective targeting populations with specific conditions.

8.0 References

Aagaard, P., Andersen, J.L., Dyhre-Poulsen, P., Leffers, A.M., Wagner, A., Magnusson, S.P. … Simonsen, E.B. (2001). A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. *The Journal of Physiology, 534*, 613-23.

Aagaard, P., Bennekou, M., Larsson, B., Andersen J.L., Olesen, J., Crameri, R. … Kjaer, M. (2007). [Abstract]. Resistance training leads to altered muscle fiber type composition and enhanced long-term cycling performance in elite competitive cyclists. *Medicine and Science in Sports and Exercise, 39*, 448-9.

Aagaard, P. & Andersen, J.L. (2010). Effects of strength training on endurance capacity in top-level endurance athletes. *Scandinavian Journal of Medicine and Science in Sports, 20*(2), 39-47.

Aagaard, P., Andersen, J.L., Bennekou, M., Larsson, B., Olesen, J.L., Crameri, R. … Kjaer, M. (2011). Effects of resistance training on endurance capacity and muscle fiber composition in young top-level cyclists. *Scandinavian Journal of Medicine and Science in Sports, 21*(6), 298-307.

Abbiss, C.R. & Laursen, P.B. (2005). Models to explain fatigue during prolonged endurance cycling. *Sports Medicine, 35*(10), 865-98.

Abbot, B.C., Bigland, B., & Ritchie, J.M. (1952). The physiological cost of negative work. *Journal of Physiology, 117*, 380-90.

Abe, T., Loenneke, J.P., Young, K.C., Thiebaud, R.S., Nahar, V.K., Hollaway, K.M. … Loftin, M. (2015). Validity of ultrasound prediction equations for total and regional muscularity in middle-aged and older men and women. *Ultrasound in Medicine & Biology, 41*(2), 557-64.

Ahtiainen, J.P, Pakarinen, A., Alen, M., Kraemer, W.J., & Häkkinen, K. (2003). Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. *European Journal of Applied Physiology, 89*, 555-63.

Barrett-O'Keefe, Z., Helgerud, J., Wagner, P.D., & Richardson, R.S. (2012). Maximal strength training and increased work efficiency: contribution from the trained muscle bed. *Journal of Applied Physiology, 113*(12), 1846-51.

Basset, D.R. JR. & Howley, E.T. (1997). Maximal oxygen uptake: "classical" versus "contemporary" viewpoints. *Medicine and Science in Sports and Exercise, 29*(5), 591-603.

Basset, D.R. JR. & Howley, E.T. (2000). Limiting factors for maximum oxygen uptake and determinants for endurance performance. *Medicine and Science in Sports and Exercise, 32*, 70-84.

Bassey, E.J., Fiatarone, M.A., O'Neill, E.F, Kelly, M., Evans, W.J., & Lipsitz, L.A. (1992). Leg extensor power and functional performance in very old men and women. *Clinical Science, 82*(3), 321-7.

Bastiaans, JJ., van Diemen, A.B., Veneberg, T., & Jeukendrup, A.E. (2001). The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. *European Journal of Applied Physiology, 86*, 79-84.

Bell, G.J., Peterson, S.R., Wessel, J., Bagnall, K., & Quinney, H.A. (1991). Physiological adaptations to concurrent endurance training and low velocity resistance training. *International Journal of Sports Medicine, 12*(4), 384-90.

Bentley, D.J., Wilson, G.J., Davie, A.J., & Zhou, S. (1998). Correlation between peak power output, muscular strength and cycle time trial performance in triathletes. *Journal of Sports Medicine and Physical Fitness, 38*(3), 201-7

Bentley, D.J., McNaughton, L.R., Thompson, D., Vleck, V.E., & Batterham, A.M. (2001). Peak power output, the lactate threshold, and time trial performance in cyclists. *Medicine and Science in Sports and Exercise, 33*(12), 2077-81.

Bigland-Ritchie, B. & Woods, J.J. (1976). Integrated electromyogram and oxygen uptake during positive and negative work. *Journal of Physiology, 260*(2), 267-77.

Bishop, D., Jenkins, D.G., Mackinnon, L.T., McEniery, M., & Carey, M.F. (1999). The effect of strength training on endurance performance and muscle characteristics. *Medicine and Science in Sports and Exercise, 31*(6), 886-91.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine, 2*, 92-8.

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377-81.

Borg, G. (1998). Borg's perceived exertion and pain scales. Champaign, IL, USA: Human Kinetics.

Bursztyn, P. (1990). Physiology for sportspeople: a serious user's guide to the body. USA: Manchester University Press.

Cannon, D.T., Kolkhorst, F.W., & Cipriani, D.J. (2007). Effect of pedaling technique on muscle activity and cycling efficiency. *European Journal of Applied Physiology, 99*(6), 659-64.

Chapman, D., Newton, M., Sacco, P., & Nosaka, K. (2006). Greater muscle damage induced by fast versus slow velocity eccentric exercise. *International Journal of Sports Medicine, 27*(8), 591-98.

Chtara, M., Chamari, K., Chaouachi, M., Chaouachi, A., Koubaa, D., Feki, Y. … Amri, M. (2005). Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *British Journal of Sports Medicine, 39*(8), 555-60.

Cleak, M.J. & Eston, R.G. (1992). Delayed onset muscle soreness: mechanisms and management. *Journal of Sport Sciences, 10*, 325-41.

Coleman, D. (2012). The physiological demands of road cycling. In J. Hopker & S. Jobson (Eds.). *Performance cycling: the science of success*. (pp.2-19). London: Bloomsbury Publishing Plc.

Corso, P., Finkelstein, E., Miller, T., Fiebelkorn, I., & Zaloshnja, E. (2006). Incidence and lifetime costs of injuries in the United States. *Injury Prevention, 12*(4), 212-18.

Cowell, J.F., Cronin, J., & Brughelli, M. (2012). Eccentric muscle actions and how the strength and conditioning specialists might use them for a variety of purposes. *Strength and Conditioning Journal, 34*(3), 33-48.

Coyle, E.F., Feltner, M.E., Kautz, S.A., Hamilton, M.T., Montain, S.J., Baylor, A.M. … Petrek, G.W. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine and Science in Sports and Exercise, 23*, 93-107.

Coyle, E.F., Sidossis, L.S., Horowitz, J.F., & Beltz, J.D. (1992). Cycling efficiency is related to the percentage of type I muscle fibers. *Medicine and Science in Sports and Exercise, 24*(7), 782-88.

Cruz-Jentoft A., Baeyens, J.P., Bauer, J.M., Boirie, Y., Cerderholm, T., Landi, F… Zamboni, M. (2010). Sarcopenia: European concensus on definition and diagnosis. *Age and Ageing, 39*(4), 412-23.

Davies, C.T. & Thompson, M.W. (1986). Physiological responses to prolonged exercise in ultramarathon athletes. *Journal of Applied Physiology, 61*(2), 611-17.

De Araújo, R., Vinicius, D., Figueira, T.R., Denadai, B.S., & Greco, C.C. (2011). Effect of cycling exercise at different pedal cadences on subsequent muscle strength. *Journal of Exercise Science and Fitness, 9*(2), 93-99.

Dibble, L.E., Hale, T.F., Marcus, R.L., Gerber, J.P., & LaStayo, P.C. (2009). High intensity eccentric resistance training decreases bradykinesia and improves quality of life in persons with Parkinson's disease: a preliminary study. *Parkinsonism and Related Disorders, 15*(10), 752-7.

Dickhuth, H.H., Yin, L., Niess, A., Röcker, K., Mayer, F., Heitkamp, H.C., & Hortsmann, T. (1999). Ventilatory, lactate-derived and catecholamine thresholds during incremental treadmill running: Relationship and reproducibility. *International Journal of Sports Medicine, 20*(2), 122-7.

Dufour, SP., Lampert, E., Doutreleau, S., Lansdorfer-Wolf, E., Billat, V.L., Piquard, F., & Richard, R. (2004). Eccentric cycle exercise: training application of specific circulatory adjustments. *Medicine and Science of Sports and Exercise, 36*(11), 1900-06.

Elmer, S.J., McDaniel, J., & Martin, J.C. (2010). Alterations in neuromuscular function and perceptual responses following acute eccentric cycling exercise. *European Journal of Applied Physiology, 110*, 1225-33.

Elmer, S.J., Hahn, S., McAllister, P., Leong, C., & Martin, J. (2012). Improvements in multi-joint leg function following chronic eccentric exercise. *Scandinavian Journal of Medicine and Science in Sports, 22*(5), 653-61.

Elmer, S.J., Danvind, J., & Holmberg, H.C. (2013). Development of a novel eccentric arm cycle ergometer for training the upper body. *Medicine and Science of Sports and Exercise, 45*, 206-11.

English, K.L., Loehr, J.A., Lee, S.M., & Smith, S.M. (2014). Early-phase musculoskeletal adaptations to different levels of eccentric resistance after 8 weeks of lower body training. *European Journal of Applied Physiology, 114*(11), 2263-80.

Enoka, R.M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology, 81*(6), 2339-46.

Ericson, M.O., Bratt, Å., Nisell, R., Arborelius, U.P., & Ekholm, J. (1986). Power output and work in different muscle groups during ergometer cycling. *European Journal of Applied Physiology, 55*, 229-35.

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

Ferketich, A.K., Kirby, T.E., & Alway, S.E. (1998). Cardiovascular and muscular adaptations to combined endurance and strength in elderly women. *Acta Physiologica Scandinavica, 164*(3), 259-67.

Folland, J.P. & Williams, A.G. (2007). The adaptations to strength training: morphological and neurological contributions to increased strength. *Sports Medicine, 37*(2), 145-68.

Foss, Ø. & Hallén, J. (2005a). Cadence and performance in elite cyclists. *European Journal of Applied Physiology, 93*(4), 453-62.

Foss, Ø. & Hallen, J. (2005b). Validity and stability of a computerized metabolic system with mixing chamber. *International Journal of Sports Medicine, 26*, 569-75.

Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., … Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *15*(1), 109-15.

Friedmann-Bette, B, Bauer, T., Kinscherf, R., Vorwald, S., Klute, K., Bischoff, D. … Billeter, R. (2010). Effects of strength training with eccentric overload on muscle adaptation in male athletes. *European Journal of Applied Physiology, 108*(4), 821-36.

Fritz, C.O., Morris, P.E., & Richler, JJ. (2012). Effect size estimates: current use, calculations, and interpretation. *Journal of Experimental Psychology: General, 141*, 2-18.

Gastin, P.B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine, 31*(10), 725-41.

Gault, M.L. & Willems, M.E.T. (2013). Aging, functional capacity and eccentric exercise training. *Aging and Disease, 4*(6), 351-63.

Gerber, J.P., Marcus, R.L., Dibble, L.E., Greis, P.E., Burks, R.T., & LaStayo, P.C. (2007a). Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction. *Journal of Bone and Joint Surgery, 89*(3), 559-70.

Gerber, J.P., Marcus, R.L., Dibble, L.E., Greis, P.E., Burks, R.T., & LaStayo, P.C. (2007b). Safety, feasibility, and efficacy of negative work exercise via eccentric muscle activity following anterior cruciate ligament reconstruction. *Journal of Orthopaedic and Sports Physical Therapy, 37*, 10-18.

Gergley, J.C. (2011). [Abstract]. Concurrent training: a comparison of high and low cadence cycle ergometry on lower-body strength in young moderately trained males. *Medicine and Science in Sports and Exercise, 43*(5), 836. Doi: 10.1249/01.MSS.0000402329.86597.e4

Goodwin, M.L., Harris, J.E., Hernández, A., & Gladden, L.B. (2007). Blood lactate measurements and analysis during exercise: a guide for clinicians. *Journal of Diabetes Science and Technology, 1*(4), 558-69.

Gross, M., Lüthy, F., Kroell, J., Müller, E., Hoppeler, H., & Vogt, M. (2010). Effects of eccentric cycle ergometer in alpine skiers. *International Journal of Sports Medicine, 31*(8), 572-76.

Guilheim, G., Cornu, C., & Guével, A. (2010). Neuromuscular and muscle-tendon system adaptations to isotonic and isokinetic eccentric exercise. *Annals of Physical and Rehabilitation Medicine, 53*(5), 319-41.

Hagberg, J.M. & Coyle, E.F. (1983). Physiological determinants of endurance as studied in competitive racewalkers. *Medicine and Science in Sports and Exercise, 15*(4), 287-89.

Haile, L., Goss, F.L., Robertson, R.J., Andreacci, J.L., Gallagher, Jr. M., & Nagle, E.F. (2013). Session perceived exertion and affective responses to self-selected and imposed cycle exercise of the same intensity in young med. *European Journal of Applied Physiology*, *116*, 1755-65.

Häkkinen, K., Alen, M., Kraemer, W.J., Gorostiaga, E., Izquierdo, M., Rusko, H. … Paavolainen, L. (2003). Neuromuscular adaptation during concurrent strength and endurance training versus strength training. *European Journal of Physiology, 89*, 42-52.

Hansen, E.A., Rønnestad, B.R., Vegge, G., & Raastad, T. (2012). Cyclists improve pedaling efficacy and performance after heavy strength training. *International Journal of Sports Physiology and Performance, 7*, 313-21.

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

Henriksson, J. & Sundberg, C.J. (2008). Generelle effekter av fysisk aktivitet. In R. Bahr (Red.), *Aktivitetshåndboken: fysisk aktivitet i forebygging og behandling*. (pp.8-36). Oslo: Helsedirektoratet.

Henriksson, J., Knuttgen, H.G., & Bonde-Petersen, F. (1972). Perceived exertion during exercise with concentric and eccentric muscle contractions. *Ergonomics, 15*, 537-44.

Herman, L., Foster, C., Maher, M.A., Mikat, R.P., & Porcari, J.P. (2006). Validity and reliability of the session RPE method for monitoring exercise training intensity. *South African Journal of Sports Medicine, 18*, 14-17.

Higbie, E.J., Cureton, K.J., Warren, G.L., & Prior, B.M. (1996). Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. *Journal of Applied Physiology, 81*(5), 2173-81.

Hoff, J., Helgerud, J., & Wisløff, U. (1999). Maximal strength training improves work economy in trained female cross-country skiers. *Medicine and Science in Sports and Exercise, 31*(6): 870-7.

Hopker, J., Passfield, L., Coleman, D., Jobson, S., Edwards, L., & Carter, H. (2009). The effect of training on gross efficiency in cycling: A review. *International Journal of Sports Medicine, 30*, 845-50.

Hopker & Jobson. (2012). How do I compare? Performance assessment. In J. Hopker & S. Jobson (Eds.). *Performance cycling: the science of success*. (pp.39-56). London: Bloomsbury Publishing Plc.

Horowitz, J.F., Sidossis, L.S., & Coyle, E.F. (1994). High efficiency of type I muscle fibers improves performance. *International Journal of Sports Medicine, 15*(3), 152-57.

Howley, E.T., Bassett, D.R., & Welch, H.G. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and Science in Sports and Exercise, 27*(9), 1292-301.

Impellizzeri, F.M., Marcora, S.M., Rampinini, E., Mognoni, P., & Sassi, A. (2005). Correlations between physiological variables and performance in high level cross country off road cyclists. *British Journal of Sports Medicine, 39*(10), 747-51.

Isner-Horobeti, M.E., Dufour, S.P., Vautravers, P., Geny, B., Coudeyre, E., & Richard, R. (2013). Eccentric exercise training: modalities, applications and perspectives. *Sports Medicine, 43*, 483-512.

Izquierdo, M. Häkkinen, K. Ibanez, J., Kraemer, W.J., & Gorostiaga, E.M. (2005). Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men. *European Journal of Applied Physiology, 94*(1-2), 70-75.

Jackson, N.P., Hickey, M.S., & Reiser, R.F. 2nd. (2007). High resistance/low repetition vs. low resistance/high repetition training: effects on performance of trained cyclists. *Journal of Strength and Conditioning Research, 21*, 289-95.

Jacobs, I. & Kaiser, P (1982). Lactate in blood, mixed skeletal muscle, and FT or ST fibres during cycle exercise in man. *Acta Physiologica Scandinavica, 114*(3), 461-66.

Jansson, E., Stensvold, D., & Ulrik, W. (2008). Helseaspekter ved styrketrening. In: R. Bahr (Ed.), *Aktivitetshåndboken – Fysisk aktivitet i forebygging og behandling* (pp.142-153). Oslo: Helsedirektoratet.

Jindrich, D.L., Besier, T.F., & Lloyd, D.G. (2006). A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics, 39*, 1611-20.

Jones, A.M. & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine, 29*(6), 373-86.

Joyner, M.J. & Coyle, E.F. (2008). Endurance exercise performance: the physiology of champions'. *Journal of Applied Physiology*, *586*, 35-44.

Knuttgen, H.G. & Klausen, K. (1971). Oxygen debt in short-term exercise with concentric and eccentric muscle contractions. *Journal of Applied Physiology, 30*(5), 632-35.

Korff, T., Romer, L.M., Mayhew, I., & Martin, J.C. (2007). Effect of pedaling technique on mechanical effectiveness and efficiency in cyclists. *Medicine and Science in Sports and Exercise, 39*(6), 991-95.

Kraemer, W.J. & Ratamess, N.A. (2004). Fundamentals of resistance training: progression and exercise prescription. *Medicine and Science in Sports and Exercise, 36*(4), 674-88.

Kristoffersen, M., Gundersen, H., Leirdal, S., & Iversen, V.V. (2014). Low cadence interval training at moderate intensity does not improve cycling performance in highly trained veteran cyclists. *Frontiers in Physiology, 31*(5), 34.

Kwon, Y.H. & Park, J.W. (2011). Different cortical activation patterns during voluntary eccentric and concentric muscle contractions: an fMRI study. *Neuro Rehabilitation, 29*(3), 253-9.

Laroche, D., Joussain, C., Espagnac, C., Morisset, C., Tordi, N., Gremeaux, V., & Casiallas, J.M. (2013). Is it possible to individualize intensity of eccentric cycling exercise from perceived exertion on concentric test? *Archives of Physical Rehabilitation and Medicine, 94*(8), 1621-27.

LaStayo, P.C., Reich, T.E., Urquhart, M., Hoppeler, H., & Lindstedt, S.L. (1999). Chronic eccentric exercise: improvements in muscle strength can occur with little demand for oxygen. *American Journal of Physiology, 276*(2), R611-15.

LaStayo, P.C., Pierotti, D.J., Pifer, J., Hoppeler, H., & Lindstedt, S.L. (2000). Eccentric ergometry: increases in locomotor muscle size and strength at low training intensities. *American Journal of Physiology. Regulatory, integrative and comparative physiology, 27*(8), 1282-88.

LaStayo, P.C., Ewy, G.A., Pierotti, D.D., Johns, R.K., & Lindstedt, S. (2003a). The positive effects of negative work: increased muscle strength and decreased fall risk in a frail elderly population. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 58*(5), M419-24.

LaStayo, P.C., Woolf, J.M., Lewek, M.D., Snyder-Mackler, L., Reich, T., & Lindstedt, S.L. (2003b). Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. *Journal of Orthopaedic & Sports Physical Therapy, 33*, 557-71.

LaStayo, P.C., Larsen, S., Smith, S., Dibble, L., & Marcus R. (2010). The feasibility and efficacy of eccentric exercise with older cancer survivors: a preliminary study. *Journal of Geriatric Physical Therapy, 33*(3), 135-40.

LaStayo, P.C., Marcus, R.L., Dibble, L.E., Smith, S.B., & Beck, S.L. (2011). Eccentric exercise versus usual-care with older cancer survivors: the impact on muscle and mobility - an exploratory pilot study. *BMC Geriatrics, 11*, 5.

Laursen, P.B. & Jenkins, D.G. (2002). The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance athletes. *Sports Medicine, 32*, 53-73.

Leong, C.H., McDermott, W.J., Elmer, S.J., & Martin, J.C. (2014). Chronic eccentric cycling improves quadriceps muscle structure and maximum cycling power. *International Journal of Sports Medicine, 35*(7), 559-65.

Levin, G.T., McGuigan, M.R., & Laursen, P.B. (2009). Effect of concurrent resistance and endurance training on physiologic and performance parameters of well-trained endurance cyclists. *Journal of Strength and Conditioning Research, 23*(8), 2280-86.

Leszczak, T.J., Olson, J.M., Stafford, J., & Brezzo, R.D. (2013). Early adaptations to eccentric and high-velocity training on strength and functional performance in community-dwelling older adults. *Journal of Strength and Conditioning Research, 27*(2), 442-8.

Lindstedt, S.L., Reich, T.E., Keim, P., & LaStayo, P.C. (2002). Do muscles function as adaptable locomotor springs? *Journal of Experimental Biology, 205*, 2211-16.

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), 631-40.

Loveless, D.J., Weber, C.L., Haseler, L.J., & Schneider, D.A. (2005). Maximal leg-strength training improves cycling economy in previously untrained men. *Medicine and Science in Sports and Exercise, 37*(7), 1231-6.

Lucía, A., Hoyos, J., & Chicharro, J.L. (2001). Preferred pedaling cadence in professional cycling. *Medicine and Science in Sports and Exercise, 33*(8), 1361-66.

Lucía, A., Hoyos, J., Pérez, M., Santalla, A., & Chicharro, J.L. (2002). Inverse relationship between VO_{2max} and economy/efficiency in world-class cyclists. *Medicine and Science in Sports and Exercise, 34*(12), 2079-84.

Lucía, A., Hoyos, J., Pérez, M., Santalla, A., Earnest, C.P., & Chicarro, J.L. (2004). Which laboratory variable is related with time trail performance time in the Tour de France? *British Journal of Sports Medicine, 38*, 636-40.

McCarthy, J.P., Agre, J.C., Graf, B.K., Pozniak, M.A., & Vailas, A.C. (1995). Compatibility of adaptive response with combining strength and endurance training. *Medicine and Science in Sports and Exercise, 27*(3), 429-36.

MacIntosh, BR., Esau, S., & Svedahl, K. (2002). The lactate minimum test for cycling: Estimation of the maximal lactate steady state. *Canadian Journal of Applied Physiology, 27*, 232-249.

Manfredi, T.G., Fielding, R.A., O'Reilly, K.P., Meredith, C.N., Lee, H.Y., & Evans, W.J. (1991). Plasma creatine kinase activity and exercise-induced muscle damage in older men. *Medicine and Science in Sports and Exercise, 23*(9), 1028-34.

Marcus, R.L., Smith, S., Morrell, G., Addison, O., Dibble, L.E., Wahoff-Stice, D., & LaStayo, P.C. (2008). Comparison of combined aerobic and high-force eccentric resistance exercise with aerobic exercise only for people with type 2 diabetes mellitus. *Physical Therapy, 88*(11), 1345-54.

Masud, T. & Morris, R.O. (2001). Epidemiology of falls. *Age and Ageing, 30*(4), 3-7.

Millet, G.P., Jaouen, B., Borrani, F., & Candau, R. (2002). Effects of concurrent endurance and strength training on running economy and VO_2 kinetics. *Medicine and Science in Sports and Exercise, 34*(8), 1351-9.

Moseley, L., Achten, J., Martin, J.C., & Jeukendrup, A.E. (2004). No differences in cycling efficiency between world-class and recreational cyclists. *International Journal of Sports and Medicine, 25*(5), 374-9.

Mueller, M., Breil, F.A., Vogt, M., Steiner, R., Lippuner, K., Popp, A., … Däpp, C. (2009). Different responses to eccentric and concentric training in older men and women. *European Journal of Applied Physiology, 107*(2), 145-53.

Mujika, I. & Laursen, P. (2012). Training methodology and periodisation for cycling. In J. Hopker & S. Jobson (Eds.). *Performance cycling: the science of success*. (pp. 58-65). London: Bloomsbury Publishing Plc.

Mukaka, M.M. (2012). A guide to appropriate use of Correlation coefficient in medical research. *Melawi Medical Journal, 24*(3), 69-71.

Nelson, A.G., Arnall, D.A., Loy, S.F., Silvester, L.J., & Conlee, R.K. (1990). Consequences of combining strength and endurance training regimens. *Physical Therapy, 70*(5), 287-94.

Nickleberry, B.L. & Brooks, G.A. (1996). No effect of cycling experience on leg cycle ergometer efficiency. *Medicine and Science in Sports and Exercise, 28*(11), 1396-401.

Nimmerichter, A., Eston, R., Bachl, N., & Williams, C. (2012). Effects of low and high cadence interval training on power output in flat and uphill cycling time-trials. *European Journal of Applied Physiology, 112*, 69-78.

Noble, B.J., Borg, G., Jacobs, I., Ceci, R., & Kaiser, P. (1983). A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Medicine and Science in Sports and Exercise, 15*(6), 523-28.

Noble B.J. & Robertson R.J. (1996) Perceived exertion. Champaign, IL: Human Kinetics.

Nogueira, F.R., Libardi, C.A., Vechin, F.C., Lixandrão, M.E., de Barros Berton, R.P., de Souza, T.M. … Chacon-Mikahil, M.P. (2013). Comparison of maximal muscle strength of elbow flexors and knee extensors between younger and older men with the same level of daily activity. *Clinical Interventions in Aging, 8*: 401-7.

Paavolainen, L., Nummela, A., & Rusko, H. (2000). Muscle power factors and VO2max as determinants of horizontal and uphill running performance. *Scandinavian Journal of Medicine in Science in Sports, 10*(5), 286-91.

Paddon-Jones, D., Muthalib, M., & Jenkins, D. (2000). The effects of a repeated bout of eccentric exercise on indices of muscle damage and delayed onset muscle soreness. *Journal of Science and Medicine in Sports, 3*, 35-43.

Pate, R.R., Macera, C.A., Bailey, S.P., Bartoll, W.P., & Powell, K.E. (1992). Physiological, anthropometric, and training correlates of running economy. *Medicine and Science in Sports and Exercise, 24*(10), 1128-33.

Paton, C.D. & Hopkins, W.G. (2001). Tests of cycling performance. *Sports Medicine, 31*(7), 489-96.

Paton, C.D., Hopkins, W.G., & Cook, C. (2009). Effects of low- vs. high-cadence interval training on cycling performance. *Journal of Strength and Conditioning Research, 23*(6), 1758-63.

Psilander, N., Frank, P., Flockhart, M., & Sahlin, K. (2015). Adding strength to endurance training does not enhance aerobic capacity in cyclists. *Scandinavian Journal of Medicine and Science in Sports, 25*(4), 353-59.

Putman, C.T., Xu, X., Gillies, E., MacLean, I.M., & Bell, G.J. (2004). Effects of strength, endurance and combined training on myosin heavy chain and fibre-tyoe distribution in humans. *European Journal of Applied Physiology, 92*(4-5), 376-84.

Raastad, T., Paulsen, G., Refsnes, P.E., Rønnestad, B.R., & Wisnes, A.R. (Red.). (2010). *Styrketrening – i teori og praksis*. Oslo: Gyldendal Undervisning.

Reeves, N.D., Maganaris, C.N., & Narici, M.V. (2004). Ultrasonographic assessment of human skeletal muscle size. *European Journal of Applied Physiology, 91*, 116-8.

Reeves, N.D., Maganaris, C.N., Longo, S., & Narici, M.V. (2009). Differential adaptations to eccentric versus conventional resistance training in older humans. *Experimental Physiology, 94*(7), 825-33.

Roig, M., O'Brien, K., Kirk, G., Murray, R., McKinnon, P., Shadgan, B., & Reid, W.D. (2009). The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. *British Journal of Sports Medicine, 43*(8), 556-68.

Rooyackers, J.M., Berkeljon, D.A., & Folgering, H.T. (2003). Eccentric exercise training in patients with chronic obstructive pulmonary disease. *International Journal of Rehabilitation Research, 26*, 47-9.

Rønnestad, B.R., Hansen, E.A., & Raastad, T. (2010a). 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), 965-75.

Rønnestad, B.R., Hansen, E.A., & Raastad, T. (2010b). In-season strength maintenance training increases well-trained cyclists' performance. *European Journal of Applied Physiology, 110*(6), 1269-82.

Rønnestad, B.R., Hansen, E.A., & Raastad, T. (2011). Strength training improves 5-min all-out performance following 185 min of cycling. *Scandinavian Journal of Sports Medicine, 21*(2), 250-59.

Rønnestad, B.R. & Mujika, I. (2014). Optimizing strength training for running and cycling endurance performance: A review. *Scandinavian Journal of Medicine and Science in Sports, 24*, 603-12.

Rønnestad, B.R., Hansen, J., Hollan, I., & Ellefsen, S. (2015). Strength training improves performance and pedaling characteristics in elite cyclists. *Scandinavian Journal of Medicine and Science in Sports, 25*, 89-98.

Saltin, B. & Åstrand, P.P. (1967). Maximal oxygen uptake in athletes. *Journal of Applied Physiology*, *23*(3), 353-358.

Santos-Concejero, J., Granados, C., Bidaurrazaga-Letona, I., Zabala-Lili, J., Irazusta, J., & Gil., S.M. (2013). Onset of blood lactate accumulation as a predictor of performance in top athletes. *RETOS. Nuevas tendencias en Educación Física, Deporte y Recreación, 23*, 67-69.

Shaw, B.S., Shaw, I., & Brown, G.A. (2009). Comparison of resistance and concurrent resistance and endurance training regimes in the development of strength. *Journal of Strength and Conditioning Research, 23*(9), 2507-14.

Sheppard, J., Hobson, S., Barker, M., Taylor, K., Chapman, D., McGuigan, M., & Newton, R. (2008). The effect of training with accentuated eccentric load counter-movement jumps on strength and power characteristics of high-performance volleyball players. International Journal of Sports Science and Coaching, 3(3), 355-63.

Sjödin, B. & Jacobs, I. (1981). Onset of blood lactate accumulation and marathon running performance. *International Journal of Sports Medicine, 2*, 23-6.

Sjödin, B., Jacobs, I., & Svedenhag, J. (1982). Changes in onset of blood lactate accumulation (OBLA) and muscle enzymes after training at OBLA. *European Journal of Applied Physiology and Occupational Physiology, 49*, 45-57.

Sjödin, B. & Svedenhag, J. (1985). Applied physiology of marathon running. *Sports Medicine, 2*(2), 83-99.

Skinner, J.S., Hutsler, R., Bergsteinova, V., & Buskirk, E.R., (1973). The validity and reliability of a rating scale of perceived exertion. *Medicine and Science in Sports and Exercise, 5*, 94-6.

Støren, Ø., Ulevåg, K., Larsen, M.H., Støa, E.M., & Helgerud, J. (2013). Physiological determinants of the cycling time trial. *Journal of Strength and Conditioning Research, 27*(9), 2366-73.

Sunde, A., Støren, Ø., Bjerkaas, M., Larsen, M.H., Hoff, J., & Helgerud, J. (2010). Maximal strength training improves cycling economy in competitive cyclists. *Journal of Strength and Conditioning Research, 24*(8), 2157-65.

Tanaka, H. & Swensen, T. (1998). Impact of resistance training on endurance performance. A new from of cross-training? *Sports Medicine, 25*, 191-200.

Teo, W., Newton, M.J., & McGuigan, M.R. (2011). Circadian rhythms in exercise performance: implications for hormonal and muscular adaptation. *Journal of Sports Science & Medicine, 10*(4), 600-06.

Vikmoen, O. (2015) Effects of heavy strength training on performance determinants and performance in cycling and running. Dissertation from the Norwegian School of Sport Sciences.

Vogt, M. & Hoppeler, H. (2014). Eccentric exercise – mechanisms and effects when used as training regime or training adjunct. *Journal of Applied Physiology, 116*(11), 1446-54.

Wood, R.H., Reyes, R., Welsch, M.A., Favaloro-Sabatier, J., Sabatier, M., Matthew, L.C. ... Hooper, P.F. (2001). Concurrent cardiovascular and resistance training in healthy older adults. *Medicine and Science in Sports and Exercise, 33*(10), 1751-8.

9.0 Attachments

Attachment 1. – The Borg scale

Borg skala:

6	**Ingen anstrengelse overhode**
7	**Ekstremt lett**
8	
9	**Meget lett**
10	
11	
12	
13	**Noe hardt**
14	
15	**Hardt (tungt)**
16	
17	**Meget hardt**
18	
19	**Ekstremt hardt**
20	**Maksimalt anstrengende**

Attachment 2. – Feeling in the legs

Følelse i beina

Veldig veldig tung	**9**
Veldig tung	**8**
Tung	**7**
Litt tung	**6**
Normal	**5**
Litt let	**4**
Lett	**3**
Veldig lett	**2**
Veldig veldig lett	**1**

Attachment 3. – VAS 10 point scale

FP:______ Uke:_______

Stølhet i beina

Sett en strek for hvor støl du føler deg i beina. Helt til venstre er *ingen stølhet* og helt til høyre er *maksimal stølhet*.

Økt: 1

Bakside

Fremside

Setet

Legg

Kommentarer:____

Økt: 2

Bakside

Fremside

Setet

Legg

Kommentarer:____

Attachment 4. – Borg CR10 Scale

CR10 skala:

0	**Ingenting**	
0.3		
0.5	**Ekstremt svak**	**Knapt merkbart**
0.7		
1	**Veldig svak**	
1.5		
2	**Svak**	**Lett**
2.5		
3	**Moderat**	
4		
5	**Sterk**	**Tung**
6		
7	**Svært sterk**	
8		
9		
10	**Ekstremt sterk**	**“maksimal”**
11		
ς		
•	**Absolutt maksimum**	**Høyest mulig**

Attachment 5. – Session RPE

15 minutter etter økta noterer en skår som beskriver et helhetsbilde av hvor høy intensiteten på hele økta var (se under). Vi ønsker at dere skal vente i 15 minutter med å gjøre denne bedømmelsen slik at ikke en eventuell meget rolig eller hard avslutning av økta skal få for stor påvirkning på helhetsbilde av intensiteten i økta. Dere skal notere et tall fra skalaen under.

Øktskår

0. **Hvile**
1. **Veldig, Veldig Lett**
2. **Lett**
3. **Moderat**
4. **Noe hardt**
5. **Hardt**
6.
7. **Veldig Hardt**
8.
9.
10. **Maksimal**t

Attachment 6. – Additional figures

Concentric peak torque (Nm) at 60°/second:

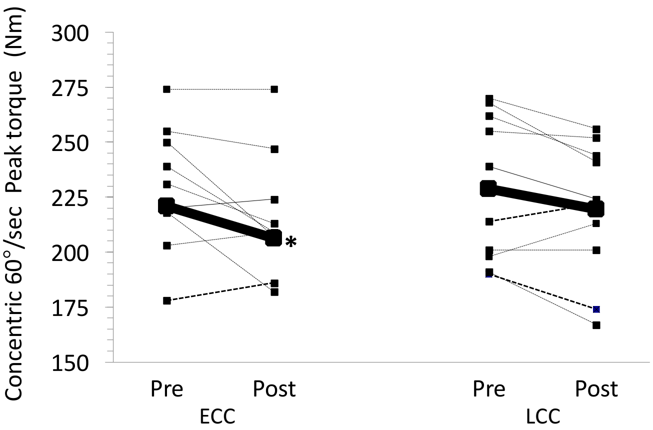

Figure 13: Peak torque (Nm) in concentric knee extension at 60°/second at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=11) and the low cadence cycling-group (LCC, n=10). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group ($p \leq 0.05$).

Muscle thickness of m. quadriceps femoris:

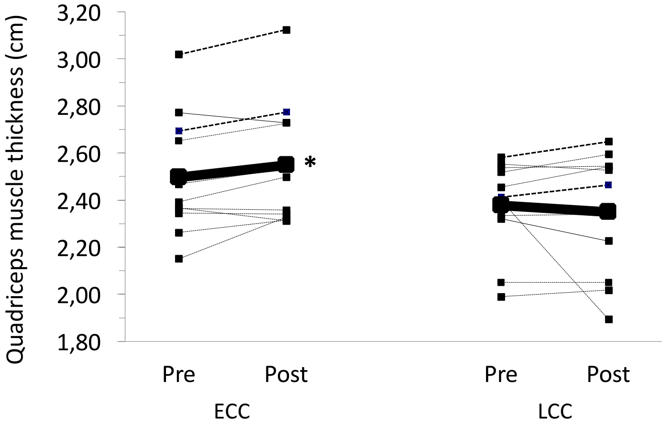

Figure 14: Muscle thickness (cm) of m. quadriceps femoris at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=12) and the low cadence cycling-group (LCC, n=11). The figure shows mean (thick line) and each individual data point (dotted lines). *=significant change pre- to post-test within group ($p \leq 0.05$).

Percentage of VO_{2max} at 4 mmol/L:

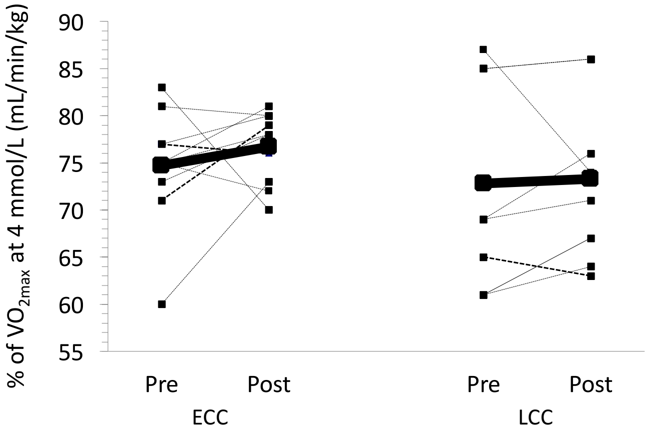

Figure 15: % of maximum oxygen consumption (VO_{2max}) at 4 mmol/L (mL/min/kg) at baseline (pre) and 10 weeks after (post) in the eccentric cycling-group (ECC, n=10) and the low cadence cycling-group (LCC, n=10). The figure shows mean (thick line) and each individual data point (dotted lines).

Mean $[La^-]_b$ at 125W, 175W, and 225W:

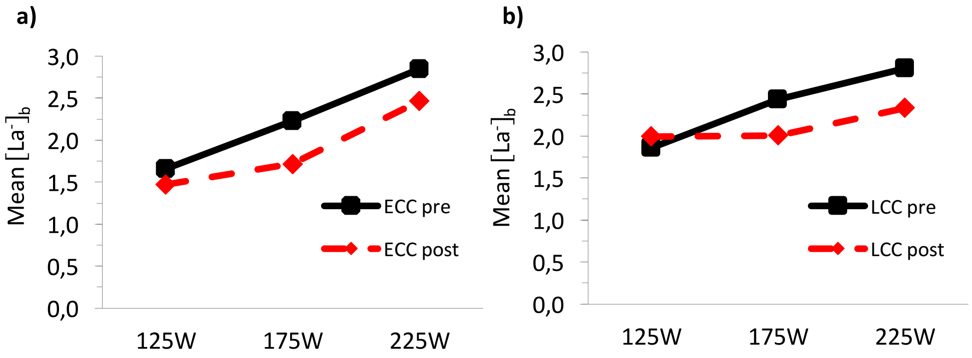

Figure 16a & b: Mean blood lactate concentration ($[La^-]_b$) at 125W, 175W, and 225W during the blood lactate profile test. Black solid line=at pre-test. Red dotted line=at post-test. **a**=eccentric cycling group (ECC), n=9 (125W), 9 (175W), 9 (225W). **b**=low cadence cycling group (LCC), n=8 (125W), 9 (175W), 7 (225W).

Forespørsel om deltagelse i forskningsprosjekt

- Effekten av eksentrisk sykling -

Bakgrunn og formål med studien:

Det foreligger dokumentasjon for at styrketrening kan forbedre prestasjonsevnen hos syklister. Man kan tenke seg at både tung styrketråkk og eksentrisk sykling kan være et tidseffektivt alternativ til tradisjonell styrketrening. Eksentrisk sykling vil si at pedalene drives bakover av en motor mens rytteren prøver å bremse denne bevegelsen. Det vil si at du bruker akkurat de samme musklene som under vanlig sykling, men at musklene strekkes istedenfor å trekke seg sammen. Eksentrisk trening er kjent for å være mer effektiv en «vanlig» konsentrisk trening for å stimulere til muskelvekst, men det er noe usikkert om det har en bedre effekt på «vanlig» konsentrisk styrkeutvikling. I dette prosjektet vil vi sammenligne eksentrisk sykling med konsentriske styrketråkk, som vil være mer spesifikk i forhold til selve sykkelprestasjonen enn eksentrisk sykling

I denne studien ønsker vi å studere treningseffekten av 8 uker med eksentrisk sykling vs. styrketråkk hos godt trente syklister med maksimalt oksygenopptak over 60 mL/kg/min. Prosjektet er initiert og ledet av Olympiatoppen og Høgskolen i Lillehammer.

Hva innebærer studien?

Selve treningsperiode varer i 8 uker og kan gjennomføres i perioden januar-mars. Det blir 2 testdager ved Høgskolen i Lillehammer før og etter treningsperioden. Du blir tilfeldig trukket til å delta i enten en gruppe som gjennomfører 2 økter pr uke med styrketråkk eller to ukentlige økter med eksentrisk sykling. Øktene tar 20-35 min og i etterkant av dette skal du gjennomføre en intervalløkt på HiL. Disse intervalløktene er de samme uansett om du er i eksentrisk sykkelgruppe eller styrketråkkgruppa og starter med lengre drag som blir kortere med høyere intensitet etter hvert som vi nærmer oss slutten på prosjektet (se tabell 1 under). Ellers oppfordrer vi deg til å ha minimum én ukentlig sykkeløkt i tillegg. Du kan ellers trene som normalt, men må dokumentere all trening i forsøksperioden.

Tabell 1: Oversikt over treningsperioden inkludert eksentrisk sykling vs. styrketråkk og de aerobe intervalløktene.

Uke	Eksentrisk sykling eller styrketråkk	RPE per drag (Borg`s CR10)	Pause	Aerob Intervall 1. økt	Aerob Intervall 2. økt
1	**Tilvenning og pre-testing**				
2	5 x 2 min	4	2	4 x 12 min (83-87% makspuls)	4 x 15 (83-87% makspuls)
3	5 x 2 min	5	2	4 x 12 min (83-87% makspuls)	4 x 15 (83-87% makspuls)
4	6 x 2 min	5	2	4 x 12 min (83-87% makspuls)	4 x 15 (83-87% makspuls)
5	6 x 2 min	6	2	5 x 8 min (88-92% makspuls)	4x10 min (88-92% makspuls)
6	7 x 2 min	7	2	5 x 8 min (88-92% makspuls)	4x10 min (88-92% makspuls)
7	8 x 2 min	7	2	5 x 8 min (88-92% makspuls)	4x10 min (88-92% makspuls)
8	8 x 2 min	7-8	2	5 x 4 min (93-98% makspuls)	5 x 6 min (93-98% makspuls)
9	7 x 2 min	7-8	2	5 x 4 min (93-98% makspuls)	5 x 6 min (93-98% makspuls)
10	6 x 2 min	7-8	2	5 x 4 min (93-98% makspuls)	
11	**Post testing**				

I uke 1 blir det først en tilvenningsøkt, der vi starter med ultralydskanning av lårmusklene. Dette gjøres for å evaluere om treningen gir muskelvekst. Deretter følger 10 min oppvarming før det blir tilvenning til styrketest av knestrekkerne sittende i et dynamometer før det gjennomføres 2 stk 6 sek sykkelspurter og avslutningsvis gjennomføres en 30 sek sykkelspurt. Testdag 1 starter med en laktatprofil som avsluttes når 4 mmol/L blodlaktat er nådd. Deretter blir det 10 minutters pause før maksimalt oksygenopptak testes. Etter 20 min pause starter dagens siste test, en 20 minutters all-out prestasjonstest, der målet er å ha høyest mulig gjennomsnittswatt. Ingen hard trening skal gjennomføres dagen før test. Alle testene blir gjennomført på samme sted, under like forhold for alle forsøkspersonene og innenfor samme tidsrom på døgnet (± 1 timer) for hver person. Samme testleder blir også benyttet. All testing vil skje Høgskolen i Lillehammer sitt idrettsfysiologiske testlaboratorium.

Hva skjer med informasjonen om deg?
Opplysningene som er innhentet om deg (før og etter- testene) og informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger og prøver gjennom en navneliste. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Forsker er underlagt taushetsplikt og data behandles konfidensielt. All informasjon og prøvene som samles inn slettes senest i 2022. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres. Prosjektet er meldt til Personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste AS.

Ved å delta i studien får du gratis testing av sentrale prestasjonsbestemmende faktorer. I tillegg får du verdifull kunnskap om hvordan eksentrisk sykling og styrketråkk påvirker utholdenhetsprestasjon og variabler knyttet til dette.

Frivillig deltakelse
Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert.

Samtykke til deltakelse i studien

Jeg, _______________________________, bekrefter at jeg har mottatt både muntlig og skriftlig informasjon og samtykker herved i å delta i prosjektet, og har muligheten til å trekke meg når som helst uten å oppgi grunn og uten at det gir noen som helst form for konsekvenser.

Lillehammer,____________

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Forsøksperson	Bent Rønnestad Førsteamanuensis (prosjektleder)

Hvis du vil melde din interesse vennlig kontakt en av oss på telefon eller mail og ta med samtykkeerklæringen på første møte. På forhånd hjertelig takk for at du vil stille opp!

Dersom det er noe som du lurer på kan du kontakte:
Joar Hansen (Prosjektmedarbeider): joar.hansen@hil.no, Tel:41007396 eller
Bent Rønnestad (Prosjektleder): bent.ronnestad@hil.no, Tel: 61 28 81 93

Vennlig hilsen

_ _ _ _ _ _ _ _ _ _ _ _
Bent Rønnestad
1.amanuensis
Høgskolen i Lillehammer