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Effects of explosive strength training on cycling performance

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Abstract

Background: Concurrent heavy strength and endurance training have been proven to give positive effects on the cycling endurance performance of well trained cyclists. Still, few studies have looked into the effect of combining explosive strength training (with lighter loads) and endurance training on muscle strength and performance indicators relevant to (road) cycling.

Aim: To investigate the effect of adding explosive strength training to cycling endurance training, and to compare the effect of concurrent explosive strength training with medium loads against concurrent heavy strength training on body composition, strength development and cycling endurance performance in well trained cyclists.

Method: 17 well trained male cyclists participated in a 12-week training intervention. The participants were randomly divided into two groups, where one group ($n = 10$) performed an explosive strength training program, and the other group ($n = 7$) performed a heavy strength training program. Both groups performed the same threshold endurance sessions on the bike. Performance indicators measured included maximal oxygen uptake ($\dot{V}O_{2max}$), cycling economy (CE), 20-minute power output, fractional utilization of $\dot{V}O_{2max}$, and anaerobic capacity measured in 5 second sprints, a Wingate test and power output at $\dot{V}O_{2max}$ (w$\dot{V}O_{2max}$). 1RM muscle strength was measured in the half squat, single leg press, toe raise and hip flexion with cable-suspended weight exercises.

Results: Both groups measured significant improvements in all the strength exercises and the 5 second seated sprint. The explosive strength training group showed significant differences in average and peak power (both absolute and relative to body mass) in the 5 second standing sprint, and average power to weight in the Wingate test from pre- to post intervention. These improvements were related to changes in body composition like reduced body mass and BMI, and increased muscle mass. The main mechanisms behind was probably increased muscle strength and muscle cross sectional area, increases in fast twitch muscle fibers, a conversion from type IIX to IIA fibers and improved neuromuscular force production like increased rate of force development. A tendency of increased average power to weight in the 20 minute all out test, as well as cycling economy measured with a load of 60% of the functional threshold power was also observed. The heavy strength training group experienced a decrease in average heart rate during the 20 minute all out test. However, since there was no improvement in average power output during the same test segment, or any improvement in $\dot{V}O_{2max}$, this decrease can not be related to improved cycling performance. No significant differences were found between the groups.

Conclusion: For this group of cyclists, the heavy strength training concept did not give the same effect as described in other studies with well trained to elite level cyclists.

When comparing the effect of heavy strength training to explosive strength training, the latter training concept resulted in more improvements on the cycling endurance performance, primarily in short term performance. However, without comparing the results to those of a control group not performing any strength training, we cannot establish this as a definite fact.

Sammendrag

Bakgrunn: Implementering av styrketrening for syklister har vært tema blant forskere, trenere og utøvere i lang tid. Det siste tiåret har vært preget av mye forskningsaktivitet, der særlig tung styrketrening har vist gode resultater på sykkelprestasjonen hos godt trente syklister. Når det gjelder eksplosiv styrketrening ser det ut til at det har blitt operert med ulike definisjoner av begrepet, og funnene er dermed tvetydige/avvikende. Det ser ut til at det hittil ikke har blitt gjennomført studier med fokus på eksplsoiv styrketrening med middels belastning kombinert med utholdenhetstrening for syklister.

Mål: Å sammenligne effekten av samtidig eksplosiv styrketrening med medium belastning og utholdenhetstrening, med tung styrketrening og utholdenhetstrening på parametre som kroppssammensetning, styrkeutvikling og utholdenhetsprestasjon.

Metode: 17 godt trente mannlige syklister deltok i en 12 ukers treningintervensjon med 2 bestemte styrkeøkter og 2 bestemte utholdenhetsøkter i uka. Syklistene ble tilfeldig delt inn i 2 grupper. Den ene gruppa trente eksplosiv styrke (3-5 x 4-6 repetisjoner og 30-39% av 1RM) kombinert med utholdenhetstrening (n = 10) og den andre gruppa trente tung styrke etter 1RM-prinsippet (3 x 4-10 repetisjoner) kombinert med utholdenhet (n = 7). Begge gruppene trente samme utholdenhetsøkter med høyere intensitet mens mengde rolig utholdenhetstrening utenom var valgfritt. I tillegg til kroppsanalyse ble det gjort målinger av maksimalt oksygenopptak ($\dot{V}O_{2max}$), arbeidsøkonomi (CE), gjennomsnittlig tråkkeffekt (watt) i en 20 minutters pretasjonstest på sykkel, utnyttingsgrad av $\dot{V}O_{2max}$, og anaerob kapasitet som 5-sekunds sittende og stående sprint, Wingate-test og tråkkeffekt ved $\dot{V}O_{2max}$ (w$\dot{V}O_{2max}$). Det ble også gjort styrkemålinger av 1 repetisjon maksimum (1RM) i øvelsene knebøy, ettbeinspress, tåhev og hoftefleksjon i kabel.

Resultat: Begge gruppene oppleved økning i muskelstyrke i alle styrkeøvelsene. De hadde også forbedret gjennomsnittlig tråkkeffekt i 5 sekunds sittende sprint, både absolutt tråkkeffekt og tråkkeffekt per kilo kroppsvekt. Gruppa som trente eksplosiv styrke hadde også forbedring i gjennomsnittlig og maksimal tråkkeffekt i stående sprint (både absolutt og relativ til kroppsvekt), og i gjennomsnittlig tråkkeffekt per kilo kroppsvekt i Wingate-testen. Forbedringene var relatert til forandringer i kroppssammensetning, hovedsaklig nedgang i kroppsvekt og BMI, og økning i muskelmasse. Mekanismene bak forbedringene var antageligvis økning i muskelstyrke og muskeltverrsnitt, økning i andel raske muskelfiber, en omdannelse fra type IIX til IIA fibertyper, og forbedret nevromuskulær kraftproduksjon som RFD (kraftutviklingsrate). I tillegg ble det observert tendenser til økning i gjennomsnittlig tråkkeffekt per kilo kroppsvekt i en 20 minutts prestasjonstest, og arbeidsøkonomi på lav intensitet (60% av terskelwatt).

Gruppa som trente tung styrke hadde nedgang i gjennomsnittlig hjertefrekvens målt

under den 20 minutter lange prestasjonstesten. Ettersom det ikke ble målt forbedringer i gjennomsnittlig tråkkeffekt i samme testsegment, og heller ikke $\dot{V}O_{2\mathrm{max}}$, kan ikke forbedringen relateres til forbedret sykkelprestasjon. Det ble ikke funnet noen signifikante forandringer mellom gruppene.

Konklusjon: For denne typen syklister hadde ikke tung styrketrening samme effekt på sykkelprestasjonen som tidligere studier der syklistene i utgangspunktet var godt trente. Ved sammenligning av de to ulike styrketreningsintervensjonene, var det eksplosiv styrketreing som resulterte i best forbedring på sykkelprestasjonen, og da primært korttidsprestasjonen. Ettersom studien ikke sammenlignet med en kontrollgruppe som kun gjennomførte utholdenhetstrening, er det vanskelig å fastslå med sikkerhet at styrketreningen var den avgjørende årsaken til disse forbedringene.

Preface

Competitive road cycling is a multidimensional, time-consuming sport demanding considerable volumes of endurance training given that the competitions can last for hours on end. The sport is unique because of the dynamic aspects of a cycling road race, where the rider's body must be able to maintain a moderately high, steady power output for prolonged periods of time, and suddenly switch to high intensity efforts of short duration in order to close gaps to attacking riders and sprint to the finish line. Complex interactions between physiological, bio-mechanical and tactical factors decides the outcome of a race (Mujika & Padilla, 2001). Scientists, coaches and athletes are always looking for better training methods to improve the performance determinants required to be a top cyclist, and implementation of strength training has received increased attention during the last two-three decades from both amateur and elite level cyclists.

Several studies have pointed towards heavy strength training, understood as performing strength exercises with heavy loads and few repetitions, having a positive effect on key cycling performance indicators. However, adding strength training to the regular endurance training also comes with potential risks and disadvantages. First of all, elite level cyclists always stay as close to the limit of the amount of physical efforts, regardless of type, that the body is able to perform while still being able to fully recover. Exceeding this limit will result in overtraining, a state where not only the cyclists performance level will drop considerably, but also his or her ability to respond to training. For riders at this level, adding strength training would come with the cost of reducing the amounts of endurance training in the training program. The possibility that delayed onset muscle soreness (DOMS) caused by the strength training workouts might impact the quality of the endurance training is another pitfall, and lastly, weight gains resulting from increased muscle mass might negatively affect the performance when cycling uphill has been used as a reason not to go down the strength training path.

What if one could alter the way the strength training exercises are performed, while still receiving the desired benefits? Explosive strength training, in the sense of using lighter loads while ensuring maximal mobilization of the muscles when performing the exercises, could be an option worth looking into. Throughout this study, we will perform a review of the current state of science on this topic, and then conduct an experiment where the effect of explosive strength training on cycling performance is compared to that of heavy strength training using groups of well-trained cyclists.

Acknowledgments

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A big thank you off course goes to the participants of the study, who took the time to spend hours of traveling, waiting and exhausting themselves in the test lab no less than three times in three months, and who put a lot of dedication into performing the training programs as best as they could.

I should also thank my employer Oslo Kommune and the management at Jeriko Skole, who has shown extensive adaptability in giving me time off from work when needed to perform the testing and follow-up of participants of the study during the intervention period. This has been a necessary prerequisite to be able to combine the work related to the study with performing my job as a elementary school teacher.

Last, but not least my sincere gratefulness for the patience and extensive efforts contributed by my significant other, Helge. Thank you for taking time off from work to assist me in the lab, for keeping the house together while I've been buried among the books and for solving technicalities whenever needed. I couldn't have done this without you.

Tine Thomasli

Tine Thomasli
Oslo, May 15th, 2020

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Acronyms

$\dot{V}CO_2$ Volume of Carbondioxide (CO_2) Production. 20, 32, 40, 44, 45
$\dot{V}O_{2max}$ Maximum Oxygen Uptake. I, III, IV, VII–X, 1, 3–7, 10–12, 14, 15, 18, 21, 22, 32, 39–42, 50, 52–56, 60
$\dot{V}O_2$ Volume of Oxygen (O_2) Consumption. VII, 4, 5, 11, 12, 20–22, 32, 33, 40, 44, 45, 50, 52, 55

BF Breathing frequency. 40, 42
BIA Bioelectric Impedance Analysis. 17
BMI Body Mass Index. I, III, 16, 17, 32, 50, 57
BPM Beats Per Minute. 42, 44, 45

CE Cycling Economy. I, III, VIII, 1, 5, 14, 18, 32, 43, 44, 55–57, 63
CSA Cross-Sectional Area. 10, 11, 53, 55–58, 62

DOMS Delayed Onset Muscle Soreness. V, 53, 62

FTP Functional Threshold Power. X, 18, 21, 29, 33, 43, 55

GE Gross Efficiency. X, 5, 20, 43, 44

HR Heart Rate. 17, 22, 29, 42, 44

LT Lactate Threshold. 5, 12
LTP Long-Term Performance. 52

RER Respiratory Exchange Ratio. 20–22, 32, 42, 44, 45
RFD Rate of Force Development. III, 9, 11, 55, 58, 62
RM Repetition Maximum. I, III, IX, X, 9, 16, 22–24, 26, 28, 29, 36, 37, 51, 63
RPE Rating of Perceived Exertion. IX, 18, 70
RPM Revolutions Per Minute. 20, 56

SD Standard Deviation. IX, 16, 28, 33, 40, 42, 44
STP Short-Term Performance. 6, 13, 56, 62

$w\dot{V}O_{2max}$ Power Output at $\dot{V}O_{2max}$. I, III, VIII, X, 1, 7, 12, 14, 21, 32, 41, 42, 53, 56, 57, 60

1. Introduction: Cycling performance and strength training

Over the years, the effect of concurrent strength and endurance training on cycling performance has been the topic of several scientific reports. Early studies suffered from non-standardized experimental designs and methodologies with disputed validity, which has led to diverging results. Only during the last decade, stable designs and widely accepted methodologies has been established to arrive at more consistent and reproducible results when looking at the effect of concurrent endurance and heavy strength training from a scientific approach.

When assessing if and to which degree strength training can improve cycling endurance performance, some performance indicators appear to have a cardinal role and should be addressed. The determinants most oftenly emphasized are the maximal oxygen uptake ($\dot{V}O_{2max}$), the fractional utilization of $\dot{V}O_{2max}$ during prolonged efforts, cycling economy, power output at maximal oxygen uptake and anaerobic capacity (also denoted as anaerobic function in some publications) (Bassett & Howley, 2000; Faria, Parker & Faria, 2005; Joyner & Coyle, 2008). In competitive road cycling, the cardiovascular function $\dot{V}O_{2max}$ is regarded crucial when measured in combination with other indicators, and usually sets the upper limit for an athletes performance level. Studies investigating the effect of concurrent endurance and strength training on $\dot{V}O_{2max}$ have reported neither positive nor negative effects on this performance indicator alone, however, it can affect other indicators enabling the athlete's ability to convert his or her $\dot{V}O_{2max}$ capability to propulsion (Aagaard et al., 2011; Rønnestad, Hansen & Raastad, 2010, 2011b; Vikmoen et al., 2015). The fractional utilization of $\dot{V}O_{2max}$ is recognized to have a clear impact on the endurance performance. Vikmoen et al. (2015) reported improvements in fractional utilization of $\dot{V}O_{2max}$ for female cyclists performing a heavy strength training regime.

Some performance indicators, such as cycling economy (CE) and power output at maximal oxygen uptake ($w\dot{V}O_{2max}$) are believed to be highly influenced by neuromuscular conditions. Some studies have found that cycling economy to be positively affected when adding strength training to the regular cycling endurance training (Rønnestad, Hansen & Raastad, 2011a; Sunde et al., 2010), while others found no effect (Aagaard et al., 2011; Bastiaans, Diemen, Veneberg & Jeukendrup, 2001; Jackson, Hickey & Reiser, 2007; Psilander, Frank, Flockhart & Sahlin, 2014; Rønnestad et al., 2010, 2011b; Rønnestad, Hansen, Hollan & Ellefsen, 2014). Concurrent endurance and strength training may inflict neuromuscular adaptions that improves $w\dot{V}O_{2max}$ (Bastiaans et al., 2001; Rønnestad et al., 2010, 2011b; Rønnestad, Hansen & Nygaard, 2016) and anaerobic capacity (Levin, Mcguigan & Laursen, 2009; Rønnestad et al., 2010; Rønnestad et al., 2014; Rønnestad, Hansen, Hollan, Spencer & Ellefsen, 2016). Anaerobic capacity, e.g. as represented by the maximal 30 seconds power measured in a Wingate test is also considered an important performance indicator (Bassett & Howley, 2000; Beattie, Carson, Lyons & Kenny, 2017; Beattie, Kenny, Lyons & Carson, 2014).

In a review focused on optimizing strength training for running and cycling endurance performance, Rønnestad and Mujika (2013) recommends heavy strength training with maximal velocity during the concentric part of the lift for both running and cycling. On the other hand, explosive strength training is recommended for runners, but not for cyclists due to lack of reproducible, positive results. A study conducted by Bastiaans et al. (2001), where strength training with low weight and a high number of repetitions (up to 30) was defined as ”explosive-type” because of high speed in the movement, weighed heavily in that conclusion.

Searching the scientific literature for “explosive strength training cyclists” yields only one study published after Rønnestad and Mujika (2013)’s review. Beattie et al. (2017) defined the explosive strength training concept as medium- to high load, high velocity movement concept and is not in line with the prescribed definition of Bastiaans et al. (2001). However, the study combined maximal and explosive strength training rather than focusing on explosive strength training alone. This underpins that a lot is still unanswered regarding the explosive strength training concept for cyclists. Investigating the effect of concurrent explosive strength- and endurance training on cycling performance for well-trained cyclists should be a daunting opportunity to explore.

2. Theory

2.1. Cycling Performance

Competitive road cycling is an endurance sport requiring high amounts of metabolic energy as the rider have to both sustain a moderately high intensity for long periods of time, and at the same time be able to produce high power output for shorter periods throughout a race. Endurance in road cycling can be defined as *the capacity to sustain a given power output for the longest possible time (...) Endurance training causes adaptions in the pulmonary, cardiovascular and neuromuscular systems that improve the delivery of oxygen from the atmospheric air to the mitochondria and enhance the control of metabolism within the muscle cells* (Jones & Carter, 2000). Improvements in cycling endurance performance is a result of these adaptions which will enhance the riders capacity to produce a given power output, and the duration of which this power output can be maintained.

The key physiological variables contributing to cycling performance was schematically put together in a performance model by Joyner and Coyle (2008). Figure 2.1 is a modified model based on the work of Joyner and Coyle (2008) and Vikmoen et al. (2015) showing which key determinants ($\dot{V}O_{2max}$, fractional utilization of $\dot{V}O_{2max}$, cycling economy, and anaerobic capacity) that are primarily affected by strength training, endurace training, or both, and how they cooperate to form the athlete's overall cycling performance.

2.1.1. Maximal Oxygen Uptake ($\dot{V}O_{2max}$)

Maximal oxygen uptake ($\dot{V}O_{2max}$) is defined as the highest rate at which oxygen can be taken up and utilized by the body during severe exercise (Bassett & Howley, 2000). It is determined by a number of physiological factors, some of which can be improved through endurance training, and some which are pretty much genetically limited. Contributing factors include the lungs' ability to exchange gases between the cardiovascular system and the respiratory system, the heart's stroke volume and maximal heart rate, the body's red blood cell count and the density of capillaries enabling the delivery of oxygenated blood to the skeletal muscles. $\dot{V}O_{2max}$ is an important variable that sets the upper limit for endurance performance because an individual can never perform above 100% of $\dot{V}O_{2max}$ over time (Bassett & Howley, 2000).

$\dot{V}O_{2max}$ has traditionally been considered as the main performance indicator to conduct the cardiorespiratory fitness in endurance sports, including road cycling. Recent research has shown, however, that $\dot{V}O_{2max}$ is not a distinguishing factor between professional cyclists and well trained amateur cyclists. In fact, several well trained cyclists have

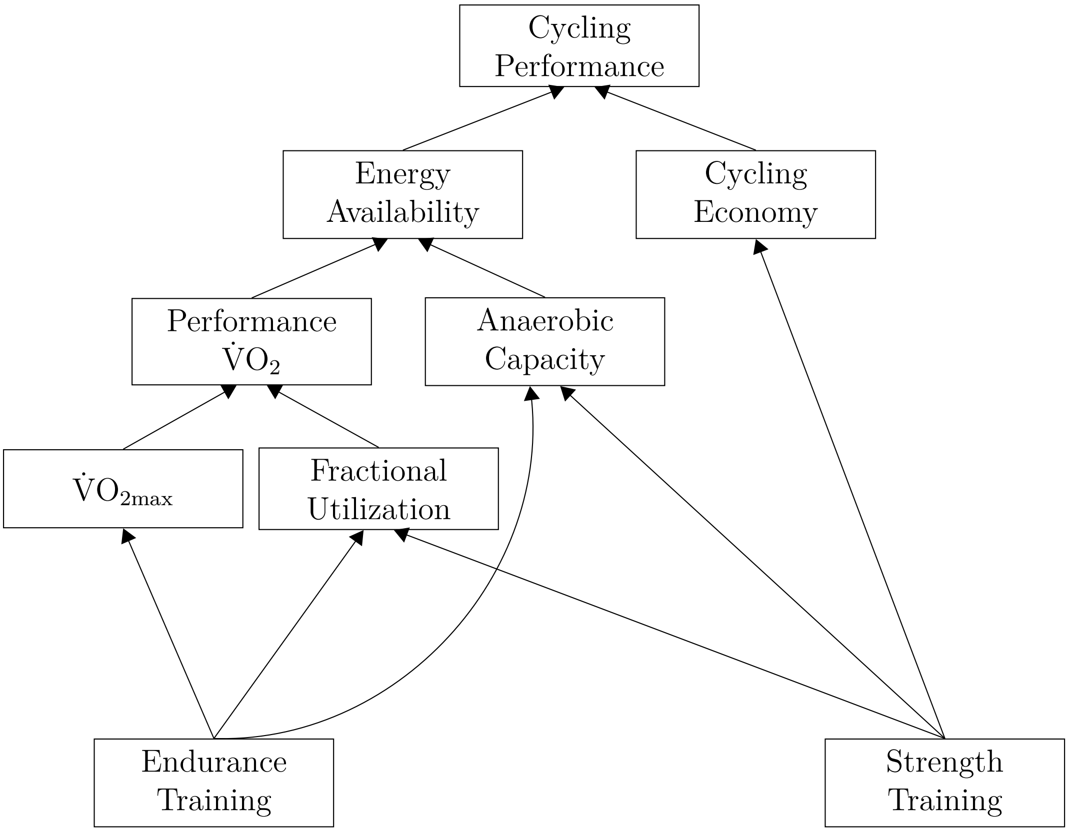

Figure 2.1.: Model of the relationship between cycling performance, cycling performance indicators, strength training and bicycle endurance training

experienced pro level $\dot{V}O_{2max}$ measurements, while there is obviously no coincidence that one group of riders is competing in world tour races while the other group isn't. $\dot{V}O_{2max}$ is still an important performance indicator, but needs to be considered as working in concert with other indicators like cycling economy and the fractional utilization of $\dot{V}O_{2max}$ (A. Lucía, Pardo, Durántez, Hoyos & Chicharro, 1998).

2.1.2. Performance $\dot{V}O_2$ and Fractional Utilization of $\dot{V}O_{2max}$

Performance $\dot{V}O_2$ *is determined by* $\dot{V}O_{2max}$ *and the percentage of* $\dot{V}O_{2max}$ *that can be maintained for the duration of an endurance event* (Vikmoen et al., 2015). This percentage is throughout the text defined and referred to as the fractional utilization of $\dot{V}O_{2max}$, in the same manner as used by Vikmoen et al. (2015). Performance $\dot{V}O_2$ is the most important factor determining energy availability over prolonged periods of time. The combination of cycling economy and performance $\dot{V}O_2$ are the key determinants of long term cycling performance.

The work conducted by Åstrand, Rodahl, Dahl and Strømme (1970) stated that endurance training will, on a general level, cause an increase in the $\dot{V}O_{2max}$. Endurance training will also impact the athletes ability to maintain a higher fractional utilization of $\dot{V}O_{2max}$ during prolonged work. After adhering to structured, intense endurance training for a period of 2-3 years, the rate of improvement of $\dot{V}O_{2max}$ will start declining, but the fractional utilization of $\dot{V}O_{2max}$ will continue growing and thereby maintaining an increase in performance level beyond this point (Bassett & Howley, 2000). The fractional utilization of $\dot{V}O_{2max}$ differs from the $\dot{V}O_{2max}$ itself in that external conditions such as road conditions, duration, mental preparedness, experience, nutrition and hydration may affect the fractional utilization, while the $\dot{V}O_{2max}$ itself is finite (Gjerset, Nilsson, Helge & Enoksen, 2015).

Edward F. Coyle (1995) demonstrated that the fractional utilization of $\dot{V}O_{2max}$ had a clear relation to the $\dot{V}O_2$ measured at lactate threshold (LT) and muscle capillary density. Two groups performing a 60 minute time trial measured the same group-level $\dot{V}O_{2max}$, but one of the groups measured a higher average power output which was credited to a higher fractional utilization of $\dot{V}O_{2max}$ at LT.

2.1.3. Cycling Economy

Gross Efficiency is defined as the ratio of power output to energy expenditure and is a key determinant of endurance cycling performance (Hopker et al., 2009). The terms efficiency and economy are used interchangeably in the literature. Throughout this text the term cycling economy (CE) will be used to describe the concept, while the term gross efficiency (GE) will be used to express the metric measuring the ratio of energy utilized for propulsion to the total metabolic energy converted in the body. In cycling this will be the oxygen cost to produce a given power output, and the most common way to express cycling economy is in *percentage of total energy expended that produces external work* (Faria et al., 2005; Foster & Lucia, 2007; Jeukendrup, Craig & Hawley, 2000; Jones & Carter, 2000; Alejandro Lucía, Hoyos, Pérez, Santalla & Chicharro, 2002, 12) . Training history, anthropometrics, biomechanics and physiology are factors determining the economy of movement (Fletcher, Esau & MacIntosh, 2009).

Alejandro Lucía et al. (2002, 12) found an inverse relationship between $\dot{V}O_{2\text{max}}$ and cycling economy in world-class cyclists. They assumed that a high cycling economy could compensate for a lower $\dot{V}O_{2\text{max}}$. A professional cyclist will travel more economically and spend less energy at the same power output as a well trained amateur cyclist with the same $\dot{V}O_{2\text{max}}$. The percentage of $\dot{V}O_{2\text{max}}$ required to produce a given workload differs between them.

2.1.4. Anaerobic Capacity

Anaerobic capacity is a common denominator describing the body's ability to develop power output beyond the limit set by the oxygen uptake. The muscles are only able to sustain anaerobic energy conversion for short durations at a time, and hence anaerobic capacity is mostly relevant for the short term performance. The term anaerobic capacity, or sometimes denoted anaerobic function often relates to the metabolic processes that do not depend on oxygen, irrespective of its availability (Faria et al., 2005).

As shown in figure 2.1, *anaerobic capacity* also has an important part in cycling endurance performance, even for cycling competitions with a duration of one or several hours. This comes down to the very nature of especially mass starts and criterium races where forming and chasing breakaways and sprint finishes are common tactical elements. Racers specializing in these types of events will both need to be able to maintain a moderately high power output for prolonged periods of time, as well as being able to repeatedly exceed their anaerobic threshold for short periods of time to keep up with the leading group.

For this reason it is important when assessing cycling performance to address the cyclists ability to produce a very high power output of brief duration. The 30 seconds all out test known as the Wingate test is widely used. The test was designed to measure the short term performance (STP), but should last long enough to cause a change of fiber recruitment from fast-twitch to slow-twitch (Bastiaans et al., 2001). When performed correctly (described in chapter 4, method), the degradation of phosphocreatine and glycogenolysis begins. After about 10 seconds a maximal rate is reached and the working muscles has to handle the loss of energy contribution and accumulation of lactate production. The mean and peak power in the Wingate test and $w\dot{V}O_{2\max}$ achieved in the stepped $\dot{V}O_{2\max}$ test demonstrate the cyclists ability to produce high power output from anaerobic metabolism Faria et al. (2005). During the recent years it has become more common to determine the sprinting ability, which also will serve as a determinant of anaerobic capacity.

Power Output at Maximal Oxygen Uptake ($w\dot{V}O_{2\max}$)

Power output at the maximal oxygen uptake ($w\dot{V}O_{2\max}$) is a composite of $\dot{V}O_{2\max}$, cycling economy and anaerobic capacity (Beattie et al., 2017; Beattie et al., 2014). In the literature the term maximal power output (W_{max}) is sometimes used, and also peak power output (W_{peak}) is found to describe this term. The terms (W_{peak}, W_{max} or $w\dot{V}O_{2\max}$) are often defined as the highest workload sustained for 2-4 minutes during progressive incremental cycling tests to exhaustion and is considered a good predictor of cycling performance when obtained during these tests (Faria et al., 2005; Hawley & Noakes, 1992; Padilla, Mujika, Cuesta & Goiriena, 1999; Padilla et al., 2001). In this text the term $w\dot{V}O_{2\max}$ will be used, and is defined as the mean power output (in watts) during the last minute of the stepped $\dot{V}O_{2\max}$ test. According to A. Lucía et al. (1998) it seems that $w\dot{V}O_{2\max}$ is a key indicator differentiating well-trained cyclists from elite cyclists.

Sprinting Ability

The last method to demonstrate the riders anaerobic endurance performance is to assess the rider's sprinting abilities. Short, explosive sprints lasting around 5 seconds has been common during the last years (Gjerset et al., 2015). Peak power occurs during the first 2-3 seconds of a sprint with fixed load (Bogdanis, Nevill & Lakomy, 1994). Then, 5 seconds should be a sufficient duration of a sprint. As described in method section, the software calculated the best 5 seconds of a range of plus minus 5 seconds to the sprint intervals in the current study.

The degradation of phosphocreatine and glycogenolysis will not occur in the same manner as the wingate test, but when sprints are performed repeatedly this degradation will affect sprint number two. Phosphocreatine stores can be reduced to around 35-55 percent of resting levels after a maximal 6 second sprint and requires more than 5 minutes to recover. Around 40 percent of the total energy is supplied from anaerobic glycolysis during a 6 second sprint, with a progressive degradation to the next sprint (Girard, Mendez-Villanueva & Bishop, 2011)

2.2. Strength Training and Cycling Endurance Performance

It has been demonstrated that endurance training alone does not stimulate improvement of neuromuscular conditions sufficiently for well-trained cyclists to achieve optimal adaptions from their training. Adding strength training to the training plan can be a good method to inflict such stimulus (Beattie et al., 2014). Strength training is defined as any kind of training intended to improve or maintain the ability to generate the largest possible force or momentum at a given velocity and way of muscular activation (Gjerset et al., 2015, p. 369).

When endurance training is combined with strength training (or vice versa) the term *concurrent training* is used in the literature. This term was first coined by Hickson (1980), when he investigated the effect of combining strength and endurance training to untrained athletes. Hickson (1980) desired to investigate whether strength training could inflict direct improvements in muscle strength or muscle hypertrophy. Åstrand and Rodahl had already in 1970 claimed that endurance training alone did not have such an effect (Åstrand et al. (1970), Hickson (1980) after Holloszy and Booth (1976)). Hickson (1980) demonstrated an impairment of gains in muscle hypertrophy and strength when combining strength training with endurance training and named this ’the interference effect’. In contrast to this finding, this concurrent training was beneficial to the endurance training, both short term and long term cycling endurance performance. This formed the foundation for the interest in the field, and the research activity has been increasing ever since (Coffey & Hawley, 2016).

When browsing available publications on strength training for cyclists, some early efforts looking into the subject were conducted in the late 1980s and the 1990s. A closer look reveals that these studies differs a lot in experimental design and test methodology. As an example, they differs in the subjects characteristics, ranging from using a total of 8 moderately trained cyclists and runners without a control group (Hickson, Dvorak, Gorostiaga, Kurowski & Foster, 1988), to using untrained subjects with no cycling background and comparing them with an inactive control group (Marcinik et al., 1991, 6). Bishop, Jenkins, Mackinnon, McEniery and Carey (1999) recruited 20 endurance trained female cyclists to perform a training intervention incorporating heavy strength training over a period of 12 weeks, but using only one strength exercise (parallel squat). Despite measuring an increase of leg strength, no improvements to cycling endurance performance was reported.

The trend with differing designs tends to be the same in the early 2000s, and the studies also differs in how the strength training is performed and how often it is performed. Concepts like explosive type strength training and high repetition strength training in cycling were introduced in this time period. The findings and conclusions were however still diverging (Bastiaans et al., 2001; Jackson et al., 2007; Paton & Hopkins, 2005).

According to Yamamoto et al. (2010) there was a lack of empirical evidence for incorporating strength training into cyclists' training programs. They also indicated that future protocols should look into using heavier loads combined with a low number of repetitions, which seems to be a common factor shared between most of the scientific work trying to relate strength training to cycling performance since approximately 2010 to date. The strength training protocols are characterized by using multiple leg exercises performed with heavier loads and few repetitions (Aagaard et al., 2011; Sunde et al., 2010), and maximal mobilization, acceleration and high speed in the concentric part of the lift (Rønnestad et al., 2010, 2011a, 2011b; Rønnestad et al., 2014; Vikmoen et al., 2015). Heavy strength training regimes have reported several positive effects on cycling endurance performance. Rønnestad et al. (2010) found improvements in mean power output at 40 minute all out time trial performed by well trained cyclists, while Aagaard et al. (2011) reported the same improvements for young top level cyclists in a 45 minute time trial.

However, as mentioned initially, the term explosive strength training is not universally defined, and it has been given different meanings throughout the history of sport sciences. According to Gjerset et al. (2015) explosive strength training and heavy/maximal strength training has traditionally been held up as two extremes within strength training. This has changed in recent times, and it is now accepted to be several commonalities between the two strength training concepts. Explosive strength capabilities can be developed with heavier loads and maximal mobilization, and while maximal mobilization is usually associated with most definitions of explosive strength training, it is now primarily associated with lighter loads (30-50% of 1RM). Rønnestad and Mujika (2013) defined explosive strength training *as exercises with external loading of 0-60% of 1RM and maximal mobilization in the concentric phase (0% of 1RM equals body weight)* (p.603). The study described in this text will adhere to this definition. In fact, Yamamoto et al. (2010) assumed that incorporating explosive strength training with a load equal to 30-40% of 1RM would benefit the performance level of well-trained cyclists. This description of load fits into the definition.

When referring to explosive strength as the ability to rapidly develop excessive force while maintaining constant muscle length, the term rate of force development (RFD) is often used (Gjerset et al., 2015, p. 370). Both explosive strength training and heavy strength training performed with maximal velocity in the concentric phase of the lift can increase RFD caused by neural activation. Improvements in RFD has been found after concurrent strength and running endurance training (Paavolainen, Häkkinen, Hämäläinen, Nummela & Rusko, 1999; Saunders et al., 2006; Taipale, Mikkola, Vesterinen, Nummela &

Häkkinen, 2012; Turner, Owings & Schwane, 2003) and concurrent strength and cycling endurance training (Aagaard et al., 2011; Sunde et al., 2010). The improvements was related to a greater movement economy. Improved blood flow to the muscles and reduced time to reach sub-maximal forces developed during each pedal stroke is commonly regarded mechanisms behind the improvement (Rønnestad & Mujika, 2013).

All muscle fiber types have the ability to grow when performing strength training. Both heavy strength training and strength training with lighter loads and maximal mobilization results in a greater hypertrophy of type II-fibers than type I. Further, when the muscles is activated during strength training, it seems like a conversion of type IIX into IIAX or IIA happens (Gjerset et al., 2015, p. 397)

When addressing the effects of strength training on the cycling endurance performance, this should happen through the key performance indicators $\dot{V}O_{2max}$, cycling economy, the fractional utilization of $\dot{V}O_{2max}$, power output at maximal oxygen uptake and anaerobic capacity. In addition, measuring body composition is regarded fundamental.

2.2.1. Body Composition

In road cycling as in any other sport where the athlete is required to move between two points in the shortest possible time, not having to waste energy carrying unnecessary weight is intrinsically important, especially for uphill cycling. Fear of gaining additional muscle mass has been a commonly used reason for not adding strength training to endurance training programs. Later research have shown however, that it is possible to achieve improved muscle strength after incorporating strength training without causing an increase in body weight in cyclists (Aagaard et al., 2011; Psilander et al., 2014; Rønnestad et al., 2010; Rønnestad et al., 2014; Sunde et al., 2010). Rønnestad et al. (2010), for example, demonstrated that heavy strength training increased thigh muscle cross-sectional area (CSA) without increasing the overall body mass. According to Beattie et al. (2017), very few studies have investigated the *interference effect* of concurrent strength training on muscle mass in trained cyclists.

2.2.2. $\dot{V}O_{2max}$

In the past, it was commonly accepted that strength training would have a negative impact on $\dot{V}O_{2max}$ (relative to body weight) due to the gained body (muscle) mass. One of the main findings and the breakthrough of Hickson (1980) was the fact that endurance adaptions, like $\dot{V}O_{2max}$ was not negatively affected when combining endurance training with strength training. The literature on concurrent strength and endurance training contains an abundance of indications that this type of training apparently does not affect the $\dot{V}O_{2max}$ for cyclists. This is reported after concurrent heavy strength training (Bishop et al., 1999; Hickson et al., 1988; Rønnestad et al., 2010) and high repetition, explosive type strength training Jackson et al. (2007), Levin et al. (2009). Even when testing the effect strength training has on $\dot{V}O_{2max}$ for untrained subjects, strength training did not result in an improvement of $\dot{V}O_{2max}$ seen in isolation (Marcinik et al., 1991, 6).

2.2.3. Cycling Economy

Studies looking at assessing the effects of concurrent strength and endurance training on cycling economy have found diverging results. Some studies found improvements after heavy strength and endurance training (Sunde et al., 2010; Vikmoen et al., 2015). Vikmoen et al. (2015) found improvements in a 40 minute time trial and credited the result to improved cycling economy. The mechanisms used to explain the improvement was increased muscle mass and muscle strength which probably enabled the cyclists to take advantage of the more economical type I fiber at higher power outputs after the intervention, while reducing the contribution from less efficient type IIX fibers. Alterations in the muscle fiber type, where type IIAX-IIX fibers were transformed to type IIA fibers was also suspected to be a contributing factor.

No improvement to cycling economy is reported after low resistance/high repetition strength training (Jackson et al., 2007) or a combination of heavy and explosive strength training (Beattie et al., 2017). Other studies assessing the effect of heavy strength training did not find improvements in cycling economy, but did find it in cycling performance itself (Aagaard et al., 2011; Rønnestad et al., 2010; Rønnestad et al., 2014). This indicates that multiple factors constitute the mechanisms behind the effects, and cycling economy can be one of them.

2.2.4. Fractional Utilization of $\dot{V}O_{2max}$

When the limitations of $\dot{V}O_{2max}$ primarily comes from central cardiovascular factors, the fractional utilization of $\dot{V}O_{2max}$ maintained during a given event is primarily linked to adaptions in the muscles (Bassett and Howley (2000) after Holloszy and Coyle (1984)). Few studies have addressed the effect of strength training on the fractional utilization of $\dot{V}O_{2max}$. Vikmoen et al. (2015), probably the first and only, found improvements in fractional utilization of $\dot{V}O_{2max}$, as well as improvements in cycling economy and cycling performance itself after a concurrent endurance and heavy strength training regime. A correlation between the change in performance $\dot{V}O_2$ and change in muscle cross-sectional area (CSA) of the quadriceps was found, and was proposed to be one of the mechanisms behind the improvement. Even though it was not measured, there was also a suggestion that increased RFD capability improved the fractional utilization of $\dot{V}O_{2max}$.

The fractional utilization of $\dot{V}O_{2max}$ is regarded as an indirect measurement of the $\dot{V}O_2$, velocity or power output at the lactate threshold (LT) (Bassett & Howley, 2000). This linkage can explain the lack of studies using the fractional utilization of $\dot{V}O_{2max}$ as a performance indicator. Then, studies assessing the effect of strength training on lactate threshold should be given attention. To represent the fractional utilization of $\dot{V}O_{2max}$ the best way, the lactate threshold should be expressed in percentage of $\dot{V}O_{2max}$ because it is determined by the $\dot{V}O_{2max}$ and work economy (Vikmoen et al., 2015). Sunde et al. (2010) and Rønnestad et al. (2014) used this variable when assessing the effect of concurrent endurance and heavy strength training on well trained cyclists. They did, however, not find any improvement of this variable (% of $\dot{V}O_{2max}$ at LT).

Aagaard et al. (2011) and Rønnestad et al. (2010) found improvements in long term cycling performance measured as a 40-45 minute time trial. They did not find improvements in $\dot{V}O_{2max}$ or cycling economy, but the mean power output increased. Even if not measured directly, this indicated an improved fractional utilization of $\dot{V}O_{2max}$. Both of these studies combined endurance training and heavy strength training.

2.2.5. Anaerobic Capacity

w$\dot{V}O_{2max}$

Research on road cyclists has shown that the potential neuromuscular adaptions from strength training can improve the anaerobic capacity. Beattie et al. (2017) reported a positive effect on w$\dot{V}O_{2max}$ after combining maximal and explosive strength training in well-trained cyclists. Since w$\dot{V}O_{2max}$ is a composite of $\dot{V}O_{2max}$, cycling economy and anaerobic capacity, the improvements should be the result of improvements to one or more of these factors. Beattie et al. (2017) related the positive effect on w$\dot{V}O_{2max}$ to cycling economy and anaerobic factors like increased maximal and explosive strength and sprinting ability on the bike. The mechanisms behind the physiological adaptions was probably related to an increased proportion of the fatigue-resistant type IIA fibers, similar to what Vikmoen et al. (2015) explained to be the reason for observing improved cycling economy and cycling performance. Rønnestad et al. (2011a) found a significant improvement of w$\dot{V}O_{2max}$ between the heavy strength training group and the control group after a 12 week heavy strength training intervention.

Wingate

Vikmoen et al. (2015) found improvements in both mean and peak power in a Wingate test, and related the findings to increased muscle strength after heavy strength training. Other heavy strength training interventions reports an effect on Wingate peak power only (Rønnestad et al., 2010; Rønnestad et al., 2014; Rønnestad, Hansen, Hollan et al., 2016). An association between increased muscle cross sectional area and Wingate peak power output is reported. Bastiaans et al. (2001) concluded that replacing a portion of endurance training with explosive type high repetition strength training could prevent a decrease in short term performance (STP) when measuring the mean power output in a Wingate test. However, many studies did not find these effects, hence the current state of scientific consensus is still unclear.

Sprinting Ability

Muscle activation plays an important role when sprinting, and considerable levels of neural activation is required. Strength training and plyometric training are some of the training methods that have improved the neuromuscular conditions affecting muscle fiber activation (Bishop, Girard & Mendez-Villanueva, 2011).

The literature of concurrent strength training on short sprinting performance in cyclists is incomplete, and the methodology differs from one study to another. Levin et al. (2009) conducted 250 m sprints together with 1km sprints during a so called closed loop test of 30 km. However, no improvements for the resistance training group was reported, and the design and methodology was pointed towards as a possible weakness.

Del Vecchio, Korhonen and Reaburn (2016) performed a study on masters athletes. It is well known that both sprint and endurance performance gradually declines with age, by as much as 6 percent each decade after passing 20 years of age. In their review about the topic they referenced previous research that have demonstrated that strength training should enhance sprint performance in masters athletes for three reasons: 1) the decrease in muscle fiber size and number because of aging may be neutralized when performing hypertrophy resistance training, 2) fast-twitch muscle fibers and motor units will be stimulated when performing heavy strength training - relevant for rapid force production, and 3) neuromuscular stimulation and muscle-tendon elasticity will be maximized when performing explosive power weight training or plyometrics.

3. Problem statement and hypothesis

The current state of the science has produced trustworthy empirical evidence that incorporating heavy strength training in the training regime of well-trained cyclists improves cycling performance. Explosive strength training, on the other hand, still leaves some definite answers to be desired, partly due to the non-deterministic use of the term itself. The number of studies addressing explosive strength training in a cycling performance context are comparatively few.

With this in mind, the aim of this study is (1) to investigate the effect of adding explosive strength training to cycling endurance training, and (2) to compare this effect with the effect of adding heavy strength training to cycling endurance training. To investigate the effect, a group of well-trained cyclists will be subject to a training intervention, and to pre- and post intervention assessments quantifying muscle strength, key physiological performance indicators such as $\dot{V}O_{2max}$, CE, $w\dot{V}O_{2max}$, fractional utilization of $\dot{V}O_{2max}$ and anaerobic capacity, as well as body composition parameters.

The study will pursue answering the question *Could explosive strength training provide similar improvements of cycling endurance performance as heavy strength training for well-trained cyclists?*

Hypothetical outcomes:

1. For well-trained cyclists, adding concurrent explosive strength training to the regular endurance training will incur an improvement in the long-term cycling performance measured in a 20-minute all out test. The average power output and power to weight, and fractional utilization of $\dot{V}O_{2max}$ will be the primary performance indicators used for evaluating the outcome of this test.
2. For well-trained cyclists, adding concurrent explosive strength training to the regular endurance training will incur an improvement in the short-term cycling performance measured in a Wingate test and seated and standing 5 second sprints. The average power output and power to weight will be the primary performance indicators used for evaluating the outcome of these tests.
3. The explosive strength training concept will incur the same improvement on the cycling endurance performance as the heavy strength training concept.

4. Materials and Methods

4.1. Experimental Design

An experimental approach was chosen in which the cyclists were divided randomly into two groups to examine and compare the effects of two different strength training regimes (pre-test - post-test randomized group design). One group performed endurance training and heavy strength training, while the other group performing endurance training and explosive strength training. The study was took place during the pre-competitive phase of the cycling calendar, and the pre-tests were completed over the course of a week. Assessments for each participant lasted for about 2 hours. Immediately following the pre-test, the participants started following a strength- and endurance training intervention program running for 12 weeks.

4.2. Participants

A total of (thirty three) competitive well-trained cyclists, ranging in age from 28-55 years were recruited to participate in this study. The cyclists fulfilled all of Jeukendrup et al. (2000)'s description of a well trained cyclist according to training and race status. That is; training frequency 3-7 times a week, training duration 60-240 min, training background 3-5 years and race days per year 0-20. A well trained competitive cyclist was also defined and qualified after these inclusion criteria; (1) the participant had not been doing lower-limb strength training during the past six months and (2) the participant had no injuries that could potentially affect the intervention and (3) the participant were planning to compete in regional or national cycling events.

The participants were informed about the risks involved when participating in the study and about their right to withdraw from the study without specify any reason at any time before signing the written consent. The study was approved by the Norwegian Center for Research Data (NSD.no).

The two intervention groups were balanced based on the participants' measured $\dot{V}O_{2max}$ and average power over 20 minutes achieved at the pre-test. This was done to ensure that no group was biased with better prerequisites for performance improvements than the other. Beyond that, the participants were randomly divided into the heavy strength training group (n=13), and the explosive strength training group (n=13). Both of the groups performed strength training and endurance training.

The criteria for excluding a participant from the study were (1) the participant

Table 4.1.: Mean ± SD Physical Characteristics at Baseline Values.

Variable	Explosive strength training group (n=10)	Heavy strength training group (n=7)
Age (y)	40.2 ± 7.9	39.7 ± 6.7
Body Mass (kg)	76.1 ± 10.4	79.4 ± 4.4
Lean Body Mass (kg)	63.9 ± 6.6	66.2 ± 3.1
BMI	24.0 ± 2.0	24.4 ± 1.9
Height (m)	1.78 ± 0.065	1.81 ± 0.061

did not perform the training program according to 85% attendance, (2) the participant did not perform the post-test, or did only perform parts of it, and (3) some technical issue experienced during the test protocol invalidated the test results. Throughout the intervention period, a total of twelve participants were excluded from the study due to injury, illness or the fact that they met the exclusion criteria. More details in the result section. Table 4.1 summarizes the baseline physical characteristics for the final number of participants, all of them males. The explosive strength training group (n=10) and the heavy strength training group (n=7).

4.3. Assessments

A pre-intervention assessment of body composition analysis, physiological performance indicators and strength testing, from now on referred to as the pre-test, was performed during the week before the intervention period started. Each participant conducted the assessments during a contiguous session lasting for two hours, except for the 1RM single leg press test, which had to be performed separately due to lack of a leg press machine in the test lab. The participants were asked to avoid high intensity training in the days leading up to the test, and had been informed that the test would be strenuous. They were also asked not to ingest food or nutritious sports hydration in the last two hours before the test. If a participant desired to ingest nutritious sports hydration during the performance test on the bike at the pre-test, the amount consumed was noted and they were told to ingest the same amount at post-test as well. Environmental conditions in the test laboratory were kept at approximately 20 degrees celsius.

4.3.1. Body Composition

The participant's height was measured and recorded along with Bioelectric Impedance Analysis (BIA) of the participant's body composition using a Tanita MC-780U Multi Frequency Segmental Body Composition Analyzer (Tanita, Tokyo, Japan). The test subject is in contact with electrodes under his or her feets and in his or her hands, from which the MC-780U emits safe electric signals at various frequencies. The signals will experience different transmission coefficients when passing through different tissue types such as hydrated muscle tissue and fat, enabling the MC-780U to determine the amount of each tissue type present between any combination of electrodes. After successful completion of the measurements, the MC-780U displays metrics including body mass, fat percentage in total, fat percentage in the trunk, left and right leg and left and right arm, body muscle mass in total, body water content, visceral fat rating, body mass index (BMI), and resting daily energy expenditure (kCal).

4.3.2. Performance Test Bike

To measure the physiological variables, a test protocol for a bike performance test was designed. The performance test was conducted using a CompuTrainer indoor bike trainer (RacerMate Inc, Seattle, USA) with a precision ergometer measuring power and cadence. The trainer was controlled by the third-party software package TrainerRoad (TrainerRoad LLC, Nevada, USA), which allows performing pre-determined test protocols in an automated fashion.

The test required using a road bike, since the differences in rider positioning that would result from using e.g. a mountain bike might have an effect on the measurements. The participants could choose if they wanted to use their own personal bike or a bike belonging to the test laboratory (two different sizes were available). The participants had to use the same bike for both the pre- and post-test. With the bike installed on the CompuTrainer, the rear wheel was inflated until reaching an air pressure reached 7 bar, and three spin-down calibrations of the CompuTrainer's power meter was performed before and during the test to ensure valid power output measurements. The trainer was set to provide a fixed resistance simulating a steady incline of 1,5%.

The participants were allowed to shift gears at their own choice, but during certain segments of the test (elaborated later) they were instructed to maintain a given power and cadence, which again would warrant shifting into a specific gear combination. The TrainerRoad software has the ability to both control the stationary trainer and to record data such as power output, heart rate (HR) and cadence. It also provides the participant a visual feedback on the test progress along with the target power output for the specific test segment. Figure 4.1 shows a visual representation of the test protocol as it appears in the

TrainerRoad software, where the horizontal axis represents time and the blue histograms represents the target power in percentage of the functional threshold power. The white horizontal bar marks 100% of the Functional Threshold Power (FTP).

The target power output is based on the test subject's FTP, which is entered into the TrainerRoad application before the test protocol is started. At the pre-test the participants themselves reported the FTP value to enter based on their own experience. For the participants that did not have an idea of their FTP due to lack of experience training with a power meter, an estimated FTP value equaling to 3 watts per kilogram of body weight (w/kg) was used. This value was not commanding, but had a guiding role/part throughout the test. For the post-test, the FTP value recorded at the pre-test was used as basis for the calculated target power displayed by TrainerRoad.

The pre- and post-test on the bike lasted for one hour and four minutes. The measurements of cycling economy (CE) at the beginning of the test also served as warm-up before the more strenuous test segments, and the participants were not allowed to do any other warm-up before the test started.

The protocol was composed as follows:

- 3 minutes free pedaling
- 5 minutes measuring of cycling economy at 60% of the functional threshold power
- 2 minutes easy free pedaling
- 5 minutes measuring of cycling economy at 70% of the functional threshold power
- 2 minutes easy free pedaling
- 5 seconds maximal sprint, seated
- 2 minutes easy free pedaling
- 5 seconds maximal sprint, standing
- 3 minutes free pedaling
- 6-7 min $\dot{V}O_{2max}$ test
- 10 minutes easy free pedaling
- 20 minutes all out test
- 5 minutes easy free pedaling
- 30 seconds Wingate test

The participants were instructed to remain seated throughout the test, except during the standing sprint, which obviously should be performed standing, and during the 20 minute all out test, where they were allowed to switch between standing and seated position at their own preference. A fan was used throughout the test to cool down the participants.

To measure the subjective feel of intensity and fatigue, the Borg scale for rating of perceived exertion (RPE) was used. This study used the revised category-ratio of Borg's

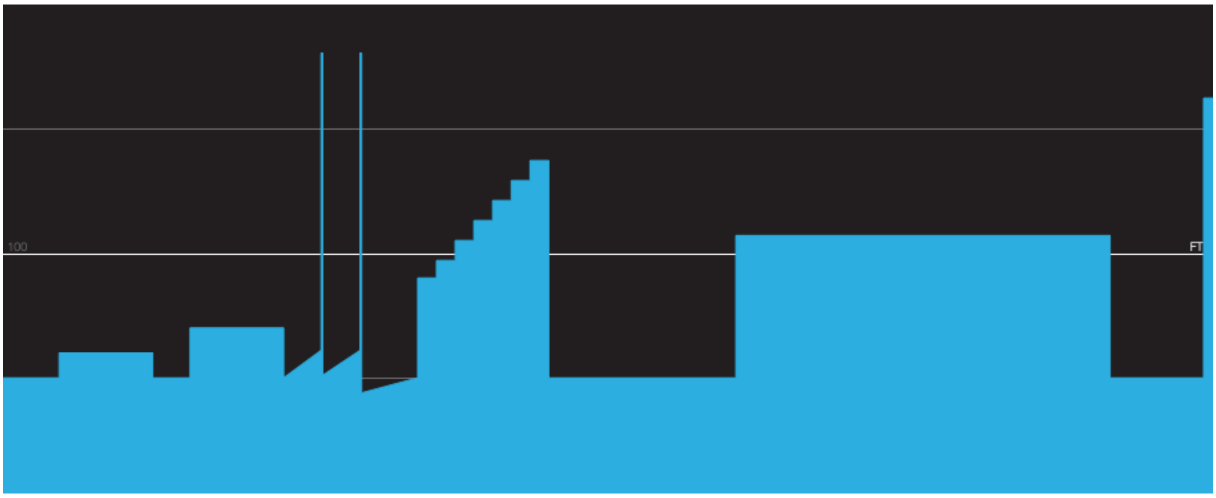

Figure 4.1.: Illustration of test protocol as shown in TrainerRoad

scale, Borg CR10 scale from 1-10, where 10 defines maximal intensity or feel (Borg, 1982).

Oxygen uptake as well as other relevant breathing-related parameters such as carbon dioxide (CO_2) production, breathing frequency and ventilation volume was measured using a metabolic cart (Oxycon Pro, Vyaire Medical, Germany). Measurements were performed in breath by breath mode with the test subject wearing a face mask (Hans Rudolph, Kansas City, USA) holding a volume and gas sensor (Triple-V, Vyaire Medical, Germany). The gas sensor was routinely calibrated using a calibration gas. The volume sensor was calibrated using the built-in volume calibration port of the Oxycon Pro. Ambient humidity was periodically read from a hygrometer and entered into the Oxycon Pro software.

Heart rate was measured throughout the test using a chest-worn heart rate sensor strap (Garmin, Kansas City, USA) transmitting data wirelessly to the computer running the TrainerRoad application.

Power output, cadence and heart rate was recorded every second (1 Hz measurement frequency). Metabolic cart measurements were recorded/averaged over 5 second periods (0.2 Hz measurement frequency).

Cycling Economy

Measuring of cycling economy started after 3 minutes of free pedaling. This test segment consisted of 2x5 minute periods at a relatively low intensity with 2 minutes of free pedaling in between. At the pre-test, the participants were instructed to pedal at a steady cadence of their own preference with a load of 60% of the estimated functional threshold power during the first 5-minute period, and 70% during the second. The participants received real-time visual feedback of their power output with respect to the target power from the TrainerRoad software. During the post-test, the target power output and cadence should be as similar as possible to what was recorded during the pre-test, not taking into account the updated functional threshold power used to guide the target power throughout the other test segments. Average $\dot{V}O_2$ uptake and $\dot{V}CO_2$ production during the final 3 minutes of each interval was recorded, and together with the average power output during the same period used to calculate and assess potential changes in the efficiency. Borg's scale was used at the start of the first interval and after both of them. The participants wore the metabolic cart's face mask through both of the intervals.

The most commonly used measure of cycling economy is gross efficiency (GE), expressed as

$$\text{GE [\%]} = \frac{\text{Work accomplished [J]}}{\text{Expended Energy [J]}} \cdot 100 \tag{4.1}$$

Using a time unit of 1 second, the work accomplished on the bike trainer during that second is equal to the power output in watts, since 1 watt = 1 J/s.

Total expended energy during that same second is found by

$$\text{Expended Energy [J]} = \frac{\dot{V}O_2 \text{ [l/min]}}{60} \cdot ((4.84 \cdot \text{RER}) + 16.89) \tag{4.2}$$

which uses the oxygen consumption and CO_2 production (indirectly through the Respiratory Exchange Ratio (RER)) to calculate the metabolic energy conversion per second (after Rønnestad, B. R.). The term GE is normally reported as percentage of total energy expenditure (Hopker et al., 2009).

Respiratory Exchange Ratio (RER) is simply the ratio between carbondioxide (CO_2) production and oxygen (O_2) consumption measured by the metabolic cart:

$$\text{RER} = \frac{\dot{V}CO_2 \text{ [l/min]}}{\dot{V}O_2 \text{ [l/min]}} \tag{4.3}$$

Sprints

Two sprints lasting for 5 seconds each were to be performed after 2 minutes of easy free pedaling following the final cycling economy interval, with 2 minutes of easy free pedaling between each sprint effort. The first sprint was conducted in a seated position, and the second standing. The participants were instructed to shift into appropriate gears and settle into a cadence of 80 revolutions per minute (RPM) before the sprint started, and then exert their absolute maximum power output for 5 seconds. The TrainerRoad software gives both a visual and audible countdown towards the start and finish of the sprint, and the test lead guided the participants through the test with verbal feedback. Since it can be challenging to time the power output perfectly, the best 5 second power within a period of ±5 seconds was found from the recorded data during post-processing.

Maximal Oxygen Uptake ($\dot{V}O_{2max}$)

After completing the sprints the participants performed 3 minutes of easy free pedaling to prepare for a stepped $\dot{V}O_{2max}$ test. They were instructed to start at a power equal to 90% of their functional threshold power (FTP) and then raise the power output by 8% of (FTP) every 60 seconds. E.g. given an FTP of 300 watts this would result in an increase of 24 watts for each step. The target power output was also during this segment of the test presented visually by the TrainerRoad software, and at the same time the test lead would monitor the power output and provide verbal feedback. The test lead would also monitor the RER, and based on it, decide if the participant should deviate from the guided target power in order to reach $\dot{V}O_{2max}$ during the final step.

The participants were allowed to shift gears and change the cadence at their own preference, and had to remain seated during the entire test. They were also given verbal feedback and encouragement to continue as long as possible. The test lasted on average for 6 minutes, but could be extended with a seventh minute if the criteria for a valid $\dot{V}O_{2max}$ test had not been fulfilled, or ended earlier if the participant had reached exhaustion. The test was ended based on these criteria; the respiratory exchange ratio (RER) had reached $\geq$ 1.05-1.10, a plateau in $\dot{V}O_2$ was encountered, or the participant was no longer able to maintain the target power output. Recorded measurements were averaged over 30 seconds. The participants were also asked about perceived exertion at the end of the test segment (Borg, 1982; Edvardsen, Hem & Anderssen, 2014; Howley, Bassett & Welch, 1995).

The average power output during the final minute before reaching $\dot{V}O_{2max}$ was recorded and regarded to represent the participant's maximal anaerobic power output (w$\dot{V}O_{2max}$).

20 Minute All-out Test

Between the stepped $\dot{V}O_{2max}$ test and the 20 minute all out test segment, the participants performed 10 minutes of active recovery. The objective of the 20 minute all-out test was to assess long term endurance performance and to derive an estimate of the participants functional threshold power (FTP). The (FTP) would later be used to control the intensity of endurance workouts on the bike. A 20 minute power output is generally accepted to be proportional with the 60 minute (FTP) if following Allen and Coggan (2010)'s test protocol. It is assumed that the stepped $\dot{V}O_{2max}$ test will have a similar effect in preparation for the 20 minute all out test as the 5 minute all-out segment as described in Allen and Coggan (2010)'s paper. The participants could choose if- and when they wanted to stand up, and they could choose their start intensity and cadence as well. Every fifth minute the participants were asked about perceived exertion which was noted along with

HR, $\dot{V}O_2$, RER and power output. Also here the participants got both visual feedback and verbally feedback to encourage them to produce the highest possible power output.

To calculate the performance $\dot{V}O_2$ during the 20 minute all out test, metabolic cart measurements were performed continuously throughout the test segment. The average $\dot{V}O_2$ during the whole 20 minute test segment was regarded to be the participant's performance $\dot{V}O_2$, and the fractional utilization of $\dot{V}O_{2max}$ was calculated as the ratio between performance $\dot{V}O_2$ and $\dot{V}O_{2max}$.

Wingate Test

The final segment of the endurance test protocol was the Wingate test. This is a 30 seconds all out test of which the average power output over the duration of the test is regarded as a valid indicator of the test subject's anaerobic capacity. The participants were instructed to start off at maximum effort from the beginning of the 30 second period, and keep pushing themselves as hard as they could manage for the full 30 seconds. In order to accomplish this they had to shift into the right gear combination and spin up their cadence before the test segment started. The test lead made a countdown from around 10 seconds before the test started to ensure that the participant was ready on time. The participant had to remain seated throughout the test. Strong verbal feedback and countdown was given throughout the duration of the test. In addition to the average power output over the test duration, the highest power output achieved during the segment was recorded. The participants were allowed to do 2 minutes of free pedaling to cool down after the Wingate test, after being allowed to catch their breath. The original wingate test was elaborated on a Monark ergometer bike with a constant braking force of 7.5 percent of the body weight. Thus, the wingate test performed in our protocol is a reminiscence adapted for use on a trainer simulating a constant incline rather than a braking force relative to the body weight.

4.3.3. Strength Tests

After completing the endurance test, the participant was given 10 minutes of rest and recovery before performing a strength test to assess their one repetition maximum (1RM) lifting capacity in three of the four strength training exercises that were to be included in the strength training programs for both intervention groups. The exercises that were tested included the half squat in smith machine, toe raise in smith machine and hip flexion with cable. The fourth exercise, single leg press, had to be tested later as the equipment required to perform that exercise was not available in the test laboratory. For more information on the strength exercises see section 4.4.1.

For each of the three exercises, a series of load/velocity measurements at low to medium weight loads was performed first. The velocity of the concentric phase was recorded using a linear encoder with associated software (Muscle Lab V10.4, Ergotest Technology AS, Porsgrunn, Norway). This assessment also served as a specific warm-up in the test protocol prior to the 1RM test. The participants performed 3 repetitions at 3 or 4 gradually increasing loads. They were instructed to perform the exercise with high speed in the concentric phase. The load progression for the squat load/velocity assessment was 44-64-74-84 kg at the pre-test. For the toe raise the progression was 64-74-84 kg, and for the hip flexion the progression was 5-10-15 kg. The test lead could decide to alter the load progression for each participant based on his or her experience and body weight, since a too light load would not yield a meaningful load/velocity curve, while a too heavy load would incur too much exhaustion before proceeding to the 1RM measurements. At the post-test the load progression was increased by 10 kg for the half squat and toe raise and by 5 kg for the hip flexion exercise. Rest periods between the sets were on average 2-3 minutes.

Following the load/velocity measurement in each exercise, the 1RM weight was measured for that same exercise before proceeding to the next one. For the half squat in smith machine the position of the barbell giving a knee angle of 90 degrees was measured, noted and marked on the machine itself before adding any weight to the barbell, to make it easier for the test lead to determine that every repetition was correctly performed and valid. The choice of 90 degrees knee angle is in line with the findings of E. F. Coyle et al. (1991) who reported that peak force during a pedal stroke was found to be at around 100 degrees knee angle. The participants were also instructed to place the feet at hip-width distance apart from each other which would simulate the foot position with the pedals on a bike. The same foot position was used in the assessment of 1RM in toe raise. When measuring 1RM in the hip flexion with cable exercise the participants supported themselves by gripping a bar in front of them to help maintain their balance and reach their maximum potential.

The perceived required effort of lifting the final load during the load/velocity measurements formed the basis for deciding the initial load for which to start testing 1RM capacity. The load was gradually increased until the participant failed to complete two attempts in a row. The number of attempts needed to reach 1RM varied between the participants. Rest periods between the lighter loads, ie. where it was obvious that the participant was far from his or her 1RM was 2 minutes and the participants got 3 minutes when they were about to reach their maximum capacity or wanted to try one more attempt after the first failure. Verbal encouragement was given when the experienced test lead could observe that the participants probably would be able to do one more lift. The post-test followed the same procedure.

The test of 1RM in the single leg press machine was performed in conjunction with instructing the participants on how to perform the strength training program at their local fitness center. The participants were instructed to perform a 10 minute warm-up on an trainer bike or a running treadmill. Testing of 1RM in single leg press started by performing a specific warm-up with gradually increasing lighter loads. The position of the moving part of the machine to be used (most commonly weight cart, footrest or the seat) giving a knee angle of 90 degrees was marked and the placement of the feet on the footrest was also here instructed to be at hip-width from each other. The participant was instructed to thrust the legs straight forward to avoid injuries due to incorrect execution. The increasing of loads, attempts and rest periods were the same as in the laboratory.

4.4. Training Programs

After completing testing and strength training instructions, the participants started the 12 week training program consisting of two weekly bicycle specific endurance workouts and two weekly strength training workouts. In addition to these four weekly training sessions, the participants performed low intensity endurance training at their own will. The participants were allowed to perform parts of the low intensity endurance training in other activity types such as running and cross-country skiing.

4.4.1. Strength Training Exercises

As was briefly touched when describing the strength tests in section 4.3.3, the strength training program for both intervention groups will consist of the following four exercises:

- Half squat in smith machine
- Single leg press
- Single leg hip flexion with cable-suspended weight
- Toe raise in smith machine or with unsupported weight

These exercises are cycling specific, especially the single leg exercises because they mimic the way a pedal stroke concentrates most of the effort to one leg at a time. These exercises have been used in several studies/experiments incorporating heavy strength training regimes which have reported positive effects on bicycle endurance performance (Rønnestad et al., 2010, 2011a, 2011b; Rønnestad et al., 2014; Vikmoen et al., 2015).

The exercises should always be performed in the order listed above.

Half Squat in Smith Machine

From now on, this exercise will simply be referred to as the squat, and whenever the term squat is used, it should be understood as the half squat performed in a smith machine.

The smith machine is a strength training machine with a barbell guided by vertical or slightly tilted rails, removing the need for the athlete to maintain balance and also reducing the risk of accidents which might be prevalent when lifting heavy weights. In some smith machines, the barbell is even wired to a counterweight, which reduces the initial weight before adding weights to the barbell.

Participants that did not have access to a smith machine at the fitness center where they performed their strength training workouts could perform the squat exercise using a regular, unguided barbell.

As previously explained, the participant should descend until achieving a 90 degrees knee angle before extending to a straight, standing position. Figures 4.2 and 4.3 shows how to perform the half squat using smith machine and using free-weight barbell, respectively.

Figure 4.2.: Half squat performed in smith machine

Figure 4.3.: Half squat performed using free-weight barbell

Single Leg Press

The single leg press should be performed using a leg press machine. Several variants exists, the most common being the angled leg press machine where the athlete is pushing a weight-loaded cart traveling on rails with an approximately 45 degrees incline, and the seated leg press machine, where the athlete is pushing horizontally towards a footrest plate.

Different types of leg press machines may require different levels of muscle strength to lift a given loading capacity. Because of that, it was important, especially for the participants in the explosive strength training group, that the pre- and post 1RM testing was performed on the same leg press machine that the participant would be using when performing the strength training.

Figure 4.4.: Single leg press using angled leg press machine

Figure 4.5.: Single leg press using seated leg press machine

Hip Flexion with Cable-Suspended Weight

When performing the hip flexion with cable-suspended weight, from now on referred to as hip flexion with cable, The athlete should maintain a straight body posture while thrusting the lifting leg forward until the thigh is horizontal. The athlete is allowed to hold on to a support in front of him or her to counter the backwards-pulling force of the weight cable.

Different types of strength training machines with cable-suspended weights can be used when performing the exercise, as long as the cable exits the machine close to the floor. The athlete needs to be aware that different types of machines can have different gear ratios between cable and weight movement, meaning that it might be necessary to test 1RM in the specific machine to be used before starting the training program.

Figure 4.6 demonstrates how to perform the hip flexion with cable while

Toe Raise

The athlete could choose whether to perform the toe raise using a smith machine or free-weight barbell. The toes should be slightly elevated (at least 4-5 cm) from the floor, which can be achieved e.g. by using a weight disc, as shown in figures 4.7 and 4.8

Figure 4.6.: Hip Flexion with Cable-Suspended Weight

Figure 4.7.: Toe Raise Performed in Smith Machine

Figure 4.8.: Toe Raise Performed using Free-Weight Barbell

4.4.2. Strength Training Programs

Both of the training programs were divided into intervals of 3 weeks at a time. That is, the groups performed the two weekly strength training sessions as the described program displayed in tables 4.2 and 4.3 according to load, sets and repetitions for the first three weeks before any change. The heavy strength training group followed the same number of sets and repetitions during the final six weeks of the intervention period. The adherence to the strength training programs was high with the explosive strength training group completed 21.8 ± 2.3 (Mean ± SD) of the planned 24 sessions and the heavy group completed 21.1 ± 1.9 sessions.

The program given to the heavy strength training group has previously been used in the cited studies conducted by Rønnestad et al. (2010, 2011a, 2011b), Rønnestad et al. (2014), Vikmoen et al. (2015). This program is based on the 1 RM principle with progressive overload, meaning the actual load could vary from one week to another, but should on average grow higher over time as the participants' muscle strength was increasing. The load should be adjusted so that the participant is able to lift the number of repetitions stated for each series, but not more. 3 series of each exercise was to be performed throughout the whole intervention period and the rest periods between the series was 3 minutes. During the first 3 weeks the first weekly strength training session consisted of 10 repetition maximum (RM) series and the second session was set to 6 RM, both of which were reduced in week four and seven, according to table 4.2. Each repetition was to be performed at high speed in the concentric phase (around 1 second) of the lift and controlled and slower speed in the eccentric phase (2-3 seconds). Behm and Sale (1993) found that the intent to perform a high velocity contraction was more important to the training effect than the actual velocity achieved when performing the exercise.

The explosive strength training group performed the strength training sessions using a load of 30% of the 1RM capacity recorded at the pre-test for the first three weeks. Every third week throughout the intervention period the load was increased with 3% of the 1RM measured at the pre-test. Each session consisted of 3, 4 or 5 series as listed

Table 4.2.: Heavy Strength Training Program

	1st session		2nd session	
Weeks	series	reps	series	reps
1 - 3	3	10	3	6
4 - 6	3	8	3	5
7 - 12	3	6	3	4

Table 4.3.: Explosive Strength Training Program

		1st session		2nd session	
Weeks	Load*	series	reps	series	reps
1 - 3	30%	5	6	3	6
4 - 6	33%	4	6	3	5
7 - 9	36%	3	6	3	4
10 - 12	39%	3	6	3	4

* Load is always referenced to the 1RM measured at the pre-test.

in tables 4.3 resulting in the same total number of repetitions per exercise per week as that of the heavy strength training program. The rest period between each series was set to 3 minutes which means that the explosive strength training group had to carry out some more rest periods compared to the heavy strength training group. Each repetition was also here performed with maximal effort in the concentric phase of the lift, and the participants were instructed to perform every repetition with maximal mobilization to achieve a greater mechanical drag in the muscle. (Gjerset et al., 2015).

The participants could choose which days during the week they preferred to perform the strength training sessions, but they were instructed to have at least a 10 minute warm up on a trainer bike or a running treadmill and then a specific warm up with lighter loads for each exercise. A recovery time of at least 48 hours between the strength training sessions was also recommended. Both of the groups were allowed to do core strength training exercises in the rest periods between the sets as long as the legs was not affected.

4.4.3. Endurance Training Program

All the participants were given the same endurance training program which consisted of 2 (3) weekly near-threshold interval sessions. A near-threshold effort is here defined as interval efforts within intensity zone 3 as defined by Olympiatoppen (2013), Tjelta, Enoksen and Tønnesen (2013), meaning that intensity during the intervals should be guided either by maintaining a steady-state heart rate (HR) at 82-87% of maximal HR or an average power output of 89-100% of the FTP as listed in table 4.4. In the literature of sports science, efforts of this intensity are usually defined as Moderate Intensity Interval Training (MIIT).

The first weekly session was a typical “low threshold/sweet spot” session with an intensity in the lower part of the zone 3. The intervals had typically longer duration with a total interval time at approximately 50-60 minutes. The second weekly session

Table 4.4.: Intensity Zones, Relationship between Heart Rate and Functional Threshold Power

Zone	% of max HR	% of FTP	Total time
1	60-72	<76	1-6 h
2	72-82	77-88	1-3 h
3	82-87	89-100	50-90 min
4	87-92	101-113	30-50 min
5	92-97	114-120	15-30 min
6	-	120-150	6-15 min

Source: Rønnestad, Knutsen, Lexberg, Kristiansen and Falk (2015)

was a typical “high threshold” session with a total interval time between 30-50 minutes. During these efforts the heart rate would gradually increase towards intensity zone 4, and sometimes reach the threshold heart rate. Every third or fourth week the training program consisted of three hard efforts. The third effort was a typical zone 4 effort with short intervals; 5x4 minutes. See Appendix B for more details.

Given that the intervention was conducted from January to early April, a time of year with reduced desirability of performing outdoor road cycling training, most of the participants performed the threshold endurance workouts indoors on trainer bikes or bike trainers. Some of the participants from both of the intervention groups had the opportunity to perform the threshold sessions in common at spin classes where the instructor coached the participants through approximately half of the described sessions on trainer bikes equipped with power meters. Other participants took advantage of the possibility to let programmable bike trainer control software (such as Zwift) control the resistance of the bike trainer according to the planned workout automatically. Participants who did not have access to a power meter when performing the bike threshold sessions used heart rate to control the intensity. Participants who wanted to join spin classes not following the training plan of the study had to adjust the training volume to end up with the same amount of intensity and time as the prescribed program.

4.4.4. Training Log

All the training activity was logged digital in Google Sheets (Google, 2019) shared between the researcher and the participant. The endurance training was logged into the different intensity zones as described in table 4.4 after each workout. In addition, the number of, and time spent with strength training were logged. The participants were asked to reflect on whether the shape felt “below” or “above” the average. They were also asked to write which type of hard effort they had done, or how much load they had lifted. There was also space to write personal feelings like “very good legs”, “illness” etc., but that was optional. Since the research lead had access to the training log, the participants got a comment occasionally, or if needed, a reminder to log performed workouts.

Together with the digital training log, there was made some “paper sheets” with a clear layout to register the strength training during the strength training sessions. This was meant as a tool to keep track of the number of sets and repetitions and loads from time to time. An example training log is shown in Appendix D.

5. Analysis and Statistics

All recorded data was initially cleaned up and post-processed by a Python script taking data in comma-separated text (CSV) format as input. Data recorded by the metabolic cart was exported directly to CSV format, while data recorded by TrainerRoad was exported in .fit format and converted to CSV using the GoldenCheetah (goldencheetah.org) software package. Body composition analysis and strength test results were manually entered into a spreadsheet and exported as CSV.

The Python script handled the following post-processing tasks:

- Calculating BMI and resting daily energy expenditure (RDEE) from body composition analysis data
- Aligning metabolic data and power, heart rate and cadence data in time. This step was required for several reasons:
  - If for some reason the participant has to stop pedaling and get off the bike, the measurements performed by TrainerRoad will pause automatically, while the metabolic cart measurements will not, causing a misalignment of measurements performed after the break
  - When metabolic cart measurements are running, but the participant is not wearing the mask, the Oxycon Pro software reduces the measurement frequency, overriding the measurement frequency set by the operator. This means the time between each record in the output file is different throughout the file.
- Calculating 30 second averages of metabolic data since the common practice is to require the $\dot{V}O_{2max}$ number to be a 30 second average
- Searching for the 5 second, 20 minute and 30 second period giving the best average power for the sprints, 20 minute all out test and Wingate tests, respectively
- Calculating average power output, max power output, average heart rate, max heart rate and average cadence for all test segments
- Calculating average $\dot{V}O_2$ uptake, average $\dot{V}CO_2$ production, max $\dot{V}O_2$ uptake (averaged over 30 seconds) and average respiratory exchange ratio (RER) for the two cycling economy (CE) segments, stepped VO2 max test and the 20 minute all out test
- Calculating efficiency for the two CE segments and for the 20 minute all out test
- Determining w$\dot{V}O_{2max}$ and RER at $\dot{V}O_{2max}$
- Calculating fractional utilization of $\dot{V}O_{2max}$ as the ratio of the best $\dot{V}O_2$ uptake over 20 minutes to the $\dot{V}O_{2max}$

- Calculating functional threshold power FTP from the maximum 20 minute average power

The combined measurements from all data sources, along with the additional calculated values were saved to a spreadsheet for further analysis. Individual test reports for each participant, with graphical representation of the data series over time were generated and saved in pdf format, and manually inspected to verify correct processing.

To describe and find relationships among variables and to detect differences among the groups, Student's t-tests was applied. An independent Student's t-test was used to compare the means between the groups at post intervention. To compare the pre-post effect between the dependent samples in each group a dependent t-test, also known as the paired Student's t-test was used. The level of significance was set to $P<0.05$ and analyses resulting in $P<0.10$ are described as tendencies.

Microsoft Excel 2003-2007 (Microsoft Corporation, Redmond, WA, USA) was used to calculate group-level means, standard deviations (SD), between group t-tests and pre to post intervention t-tests for all relevant variables. The statistical analyses was controlled using SPSS version 26.0 (SPSS Inc, Chicago, IL). All data in the text, figures and tables are presented as means ± standard deviations (SD).

Weight-adjustment of power and $\dot{V}O_2$ measurements

As pointed out by Vikmoen et al. (2015), performing cycling performance tests on a stationary trainer does not account for the way variations in body weight affects performance, especially when riding up hill. To compensate for this, any measurements of power output and oxygen uptake are dually reported with both the raw measured value (in watts and liters per minute, respectively) and a value compensated for body weight (watts per kilogram and milliliters per minute per kilogram, respectively).

6. Results

There were no significant differences between the explosive strength training group and the heavy strength training group at baseline with respect to variables in muscle strength, body composition, and physiology.

6.1. Excluded Participants

As mentioned in the method section, a total of twelve participants were excluded from the study due to injury, illness or the fact that they met the exclusion criteria. Three of the participants left the study due to illness. Two had to be excluded because of technical problems during the test, resulting in one or more variables missing. One participant had to be excluded due to an injury unrelated to the study. One participant had to be excluded after not following the training program. And another one had to be excluded after not being able to complete the post-test because he was experiencing muscle cramps. Finally, three participants left the study after the pre-test without giving any reason.

Test results from the excluded participants were excluded from the analysis. The final number of participants in each group ended up at n=7 for the heavy strength training group, and n=10 for the explosive strength training group. By coincidence, the highest number of excluded participants was experienced in the heavy strength training group.

6.2. Performed Training

Figure 6.1 shows the number of training hours performed by each intervention group. While the group means are approximately the same, there is a higher variance in the number of endurance training hours performed by the explosive strength training group (91 ± 45). The heavy strength training group performed 86.5 ± 31.5 hours of endurance training. The adherence to the strength training program was higher in the explosive strength training group (88.6 ± 11.3%). The heavy strength training group on their hand fulfilled 78.6 ± 18.3% of the 24 strength training sessions. Significance difference (level) between the groups in total duration, (P=0.18). This indicates that the difference in adherence between the groups was not significant and that we can not determine if it affected the measured result.

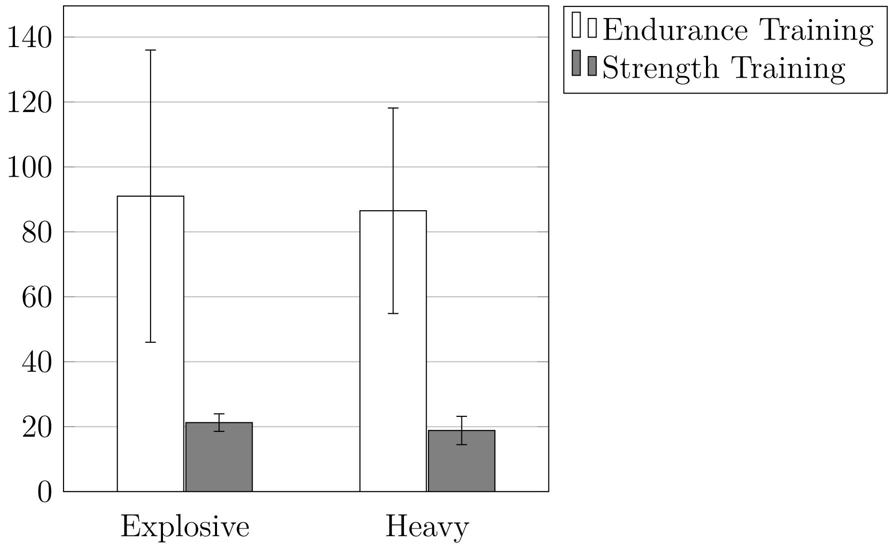

Figure 6.1.: Mean ± SD logged training hours per group

6.3. Strength Exercises

The significance level between the groups was (P=0.09) in 1RM squat, which means that no significant difference was found from pre to post intervention. However, the level tells us about a tendency towards a bigger increase in strength for the squat exercise in the heavy strength training group. This tendency is not found in the three other strength exercises between the groups. The heavy strength training group increased 59 ± 41.5% (P=0.002) while the increase was 32,3 ± 19% (P=0.001) in the explosive strength training group.

Both of the groups increased the strength significantly from pre to post intervention in all the strength exercises (P<0.01). The explosive strength training group showed a significant increase in single leg press (P=0.02), hip flexion (P=0.002) and toe raise (P=0.01). The heavy strength training group had a significant increase in single leg press (P=0.04), hip flexion (P=0.01) and toe raise (P=0.01).

Table 6.1.: Mean ± SD data of 1RM in strength exercises from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Squat (kg)	147 ± 30.6	190.9 ± 29.2	32.3 ± 19*
Single leg press (kg)	137.3 ± 30	181.5 ± 34.8	35.6 ± 32.6*
Hip Flexion (kg)	28 ± 7.2	34.8 ± 5.5	28.3 ± 25.8*
Toe raise (kg)	156.3 ± 25.3	192 ± 32.5	23.7 ± 16.7*

Heavy strength training group

	Pre	Post	% change
Squat (kg)	123.2 ± 25.8	189.1 ± 28.9	59 ± 41.5*
Single leg press (kg)	137.1 ± 41.5	169 ± 38	31.3 ± 42*
Hip Flexion (kg)	27.9 ± 2.7	38.6 ± 7	39.8 ± 29*
Toe raise (kg)	149.4 ± 20	194 ± 42.7	30.4 ± 21*

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

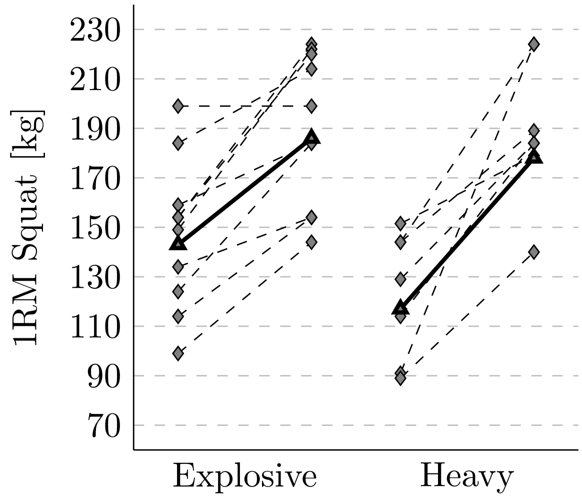

Figure 6.2.: Pre-post development of 1RM Squat per group. Bold line represents group average.

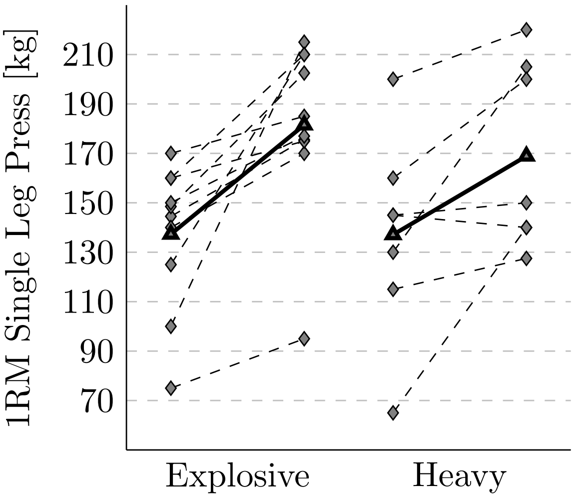

Figure 6.3.: Pre-post development of 1RM Single Leg Press per group. Bold line represents group average.

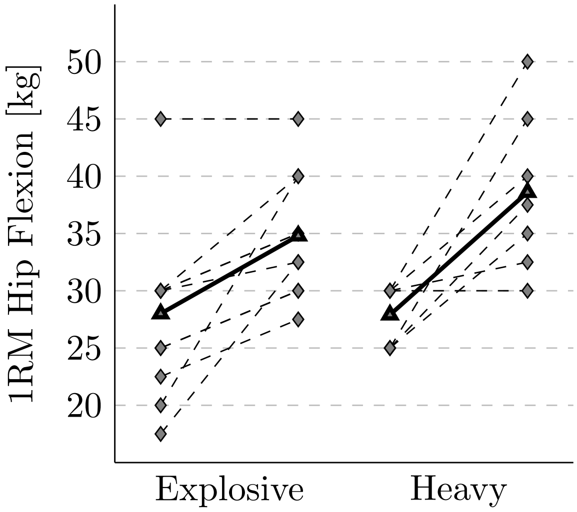

Figure 6.4.: Pre-post development of 1RM Hip Flexion per group. Bold line represents group average.

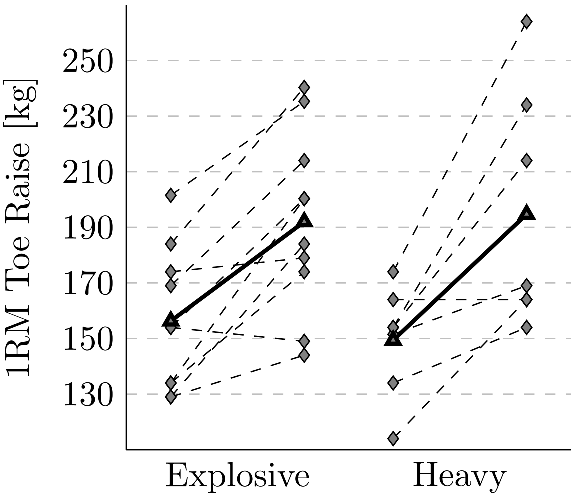

Figure 6.5.: Pre-post development of 1RM Toe Raise per group. Bold line represents group average.

6.4. Body Composition

During the training intervention there were no significant differences in body composition between the groups from pre to post intervention.

However, the explosive strength training group had a significant within group decrease from pre to post intervention in body mass (P=0.05), and BMI (P=0.03). In addition, there was an increase in muscle mass (P=0.01). The heavy strength training group, on the other hand, showed no significant changes in body composition (P>0.05). Between the groups no significant differences was identified.

Table 6.2.: Mean ± SD data of body composition measurements from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Body mass (kg)	76.1 ± 10.4	75.0 ± 10.4	-1.44 ± 2.0*
Lean body mass (kg)	63.9 ± 6.6	64 ± 6.8	0.05 ± 2.1
Body mass index (BMI)	24.0 ± 2.0	23.6 ± 2.0	-1.5 ± 1.9*
Fat % total	15.7 ± 4.7	14.4 ± 4.3	-7.5 ± 7.7
Muscle mass (%)	80.1 ± 4.5	81.3 ± 4.1	1.5 ± 1.5*

Heavy strength training group

	Pre	Post	% change
Body mass (kg)	79.4 ± 4.4	79.1 ± 4.0	-0.31 ± 2.0
Lean body mass (kg)	66.2 ± 3.1	66 ± 2.5	-0.38 ± 2.1
Body mass index (BMI)	24.4 ± 1.9	24.3 ± 1.5	-0.3 ± 1.9
Fat % total	16.5 ± 3.3	16.6 ± 2.2	2.6 ± 0.1
Muscle mass (%)	79.3 ± 3.2	79.3 ± 2.2	-0.04 ± 1.9

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

6.5. Physiological Performance Indicators

6.5.1. 20 Minute All-out Performance

No significant differences between the groups were found for the variables measured during the 20 minute all-out performance test.

A significance level of (P=0,08) in average power to weight was found in the explosive strength training group, however it is still not significant. The only variable where the explosive strength training group measured a significant difference from pre- to post was a decline in breathing frequency (P=0,05). The heavy strength training group measured a significant decline in average heart rate (P=0,001). They also had a decrease in average power and average power to weight, but not statistically significant.

The percentage of $\dot{V}O_{2max}$ maintained during the 20 minute all-out performance test, referred to as the fractional utilization of $\dot{V}O_{2max}$ showed no significant numbers, neither in the explosive strength training group (P=0,93) nor in the heavy strength training group (P=0,23). The heavy strength training group measured a decline on this performance indicator from pre to post test.

Figures 6.6 and 6.7 shows each participant's pre- to post development of 20-minute average power and 20-minute average fractional utilization of $\dot{V}O_{2max}$, respectively. Group-level data are given in table 6.3 (all data in the table represents the average measured over the full 20 minutes the test lasted for).

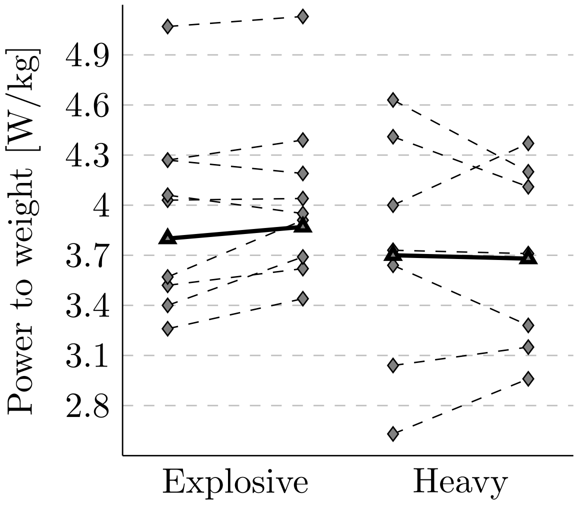

Figure 6.6.: Pre-post development of 20 minute all out test average power to weight per group. Bold line represents group average.

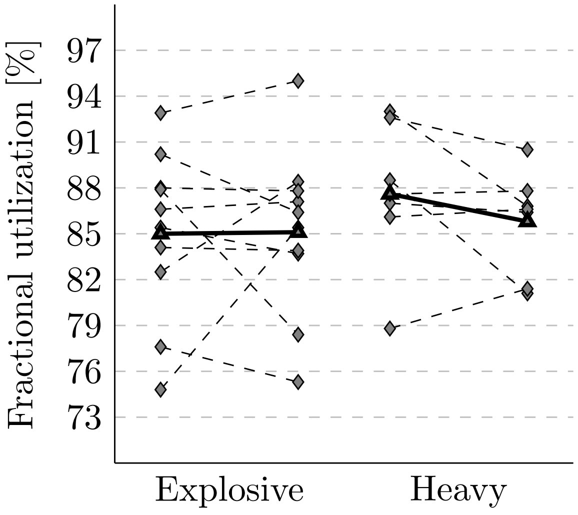

Figure 6.7.: Pre-post development of fractional utilization during 20 minute all out test per group. Bold line represents group average.

Table 6.3.: Mean ± SD data of 20 minute all out test from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Power (W)	284 ± 50.3	286.6 ± 49.6	1.0 ± 3.5
Power to weight (W/kg)	3.78 ± 0.73	3.87 ± 0.72	2.6 ± 4.2
$\dot{V}O_2$ (l/min)	3.70 ± 0.61	3.75 ± 0.61	1.7 ± 7.0
$\dot{V}O_2$ to kg (ml/kg/min)	49.3 ± 9.1	50.5 ± 8.4	3.0 ± 7.7
$\dot{V}O_2$ to $\dot{V}O_{2max}$**	0.850 ± 0.055	0.851 ± 0.054	0.4 ± 6.7
$\dot{V}CO_2$ (l/min)	3.54 ± 0.57	3.53 ± 0.54	0.5 ± 9
Cycling Economy (GE, %)	21.5 ± 2.0	21.3 ± 1.1	-0.03 ± 9.2
Heart rate (bpm)	171 ± 5	170 ± 6	-0.8 ± 2.4
RER	0.95 ± 0.03	0.94 ± 0.08	-0.1 ± 8.0
Breathing frequency (1/min)	46.1 ± 9.1	43.7 ± 6.6	-4.3 ± 6.6*

Heavy strength training group

	Pre	Post	% change
Power (W)	294.2 ± 47.9	290.4 ± 42.5	-0.5 ± 10.2
Power to weight (W/kg)	3.73 ± 0.71	3.68 ± 0.56	-0.3 ± 9.0
$\dot{V}O_2$ (l/min)	3.99 ± 0.44	4.03 ± 0.48	1.4 ± 9.5
$\dot{V}O_2$ to kg (ml/kg/min)	50.4 ± 6.2	51.1 ± 6.5	1.6 ± 8.3
$\dot{V}O_2$ to $\dot{V}O_{2max}$**	0.876 ± 0.047	0.858 ± 0.034	-2.0 ± 4.1
$\dot{V}CO_2$ (l/min)	3.91 ± 0.46	3.87 ± 0.61	-1.2 ± 7.4
Cycling Economy (GE, %)	20.4 ± 1.7	20.0 ± 1.0	-1.3 ± 6.5
Heart rate (bpm)	170 ± 8	166 ± 7	-2.7 ± 0.9*
RER	0.97 ± 0.06	0.95 ± 0.05	-2.0 ± 5.8
Breathing frequency (1/min)	45.3 ± 3.3	44.7 ± 6.4	-1.2 ± 12.4

[*] indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

[**] Ratio of average $\dot{V}O_2$/kg during 20 min all out test (Performance $\dot{V}O_2$) compared to $\dot{V}O_{2max}$/kg measured during stepped $\dot{V}O_{2max}$ test, also denoted as fractional utilization of $\dot{V}O_{2max}$.

6.5.2. $\dot{V}O_{2max}$ and $w\dot{V}O_{2max}$

There were no significant differences in $\dot{V}O_{2max}$ or the other variables measured in the stepped $\dot{V}O_{2max}$ test between the groups.

Further, although the mean $\dot{V}O_{2max}$ (ml/kg/min) was higher at the end of the intervention, the change was not significant for either group. The $w\dot{V}O_{2max}$ resulted in minimal change on group level.

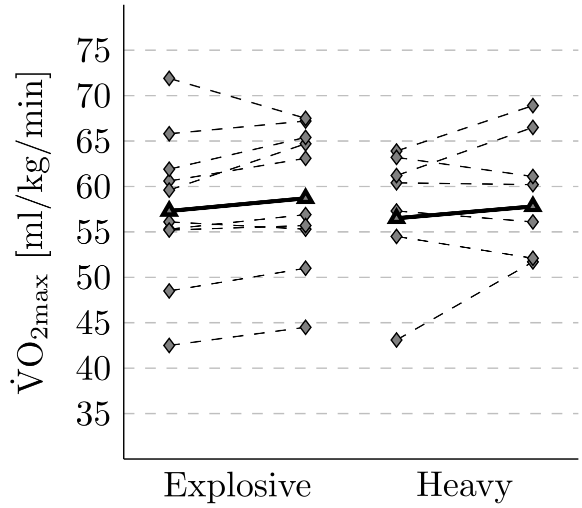

Figure 6.8.: Pre-post development of $\dot{V}O_{2max}$ to weight per group. Bold line represents group average.

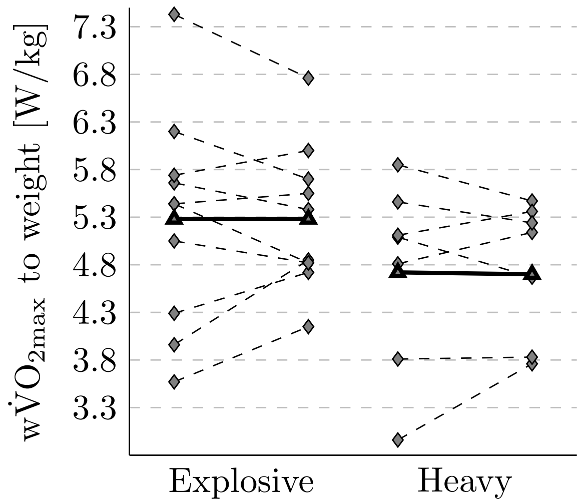

Figure 6.9.: Pre-post development of $w\dot{V}O_{2max}$ to weight per group. Bold line represents group average.

Table 6.4.: Mean ± SD data of $\dot{V}O_{2max}$ test from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
$\dot{V}O_{2max}$ (l/min)	4.35 ± 0.62	4.40 ± 0.61	1.2 ± 4.1
$\dot{V}O_{2max}$ to weight (ml/kg/min)	57.7 ± 8,3	59.1 ± 7.7	2.7 ± 4.1
w$\dot{V}O_{2max}$ (W)	393.9 ± 59.5	391.1 ± 45.0	-0.2 ± 11.0
w$\dot{V}O_{2max}$ to weight (W/kg)	5.3 ± 1.1	5.3 ± 0.8	1.7 ± 11.8
Max Heart Rate (BPM)	182 ± 8	182 ± 7	0.0 ± 2.0
RER	1.18 ± 0.11	1.15 ± 0.15	-2.1 ± 13.1
Breathing frequency (1/min)	54.9 ± 9.4	55.0 ± 6.5	2.4 ± 16.9

Heavy strength training group

	Pre	Post	% change
$\dot{V}O_{2max}$ (l/min)	4.56 ± 0.53	4.69 ± 0.47	3.5 ± 10.3
$\dot{V}O_{2max}$ to weight (ml/kg/min)	57.7 ± 7.2	59.5 ± 6.7	3.8 ± 8.9
w$\dot{V}O_{2max}$ (W)	373.0 ± 69.6	376.6 ± 49.0	2.7 ± 13.4
$\dot{V}O_{2max}$ to weight (W/kg)	4.7 ± 1.0	4.8 ± 0.7	2.9 ± 12.0
Max Heart Rate (BPM)	181 ± 7	177 ± 8	-2.3 ± 1.6
RER	1.15 ± 0.11	1.14 ± 0.07	-0.7 ± 7.9
Breathing frequency (1/min)	54.3 ± 7.0	55.7 ± 7.2	2.9 ± 7.3

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

6.5.3. Cycling Economy

No significant differences in cycling economy was measured between the groups, neither for 60% of functional threshold power output or 70% of functional threshold power output. However, the explosive strength training group increased the cycling economy at 60% of FTP with 3.6 ± 5.6% which resulted in a significance level of P=0.08. The heavy group measured a decline. Further, none of the groups displayed a significant change in cycling economy at 70 percent from pre to post intervention period.

Figures 6.10 and 6.11 shows each participant's pre- to post development of gross efficiency at 60% and 70% of functional threshold power, respectively. Group-level data are given in tables 6.5 and 6.6.

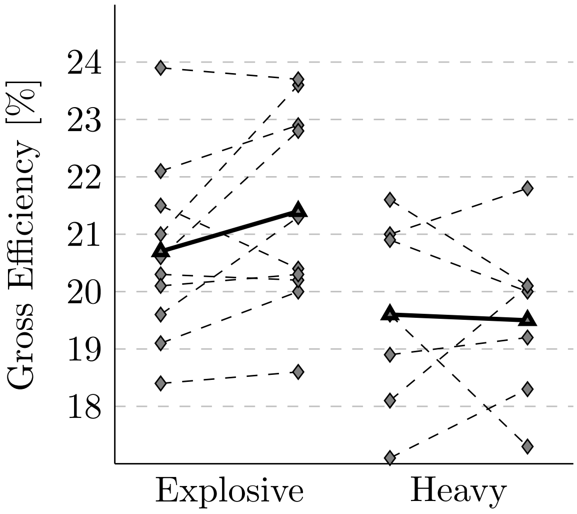

Figure 6.10.: Pre-post development of Gross Efficiency at 60% of FTP per group. Bold line represents group average.

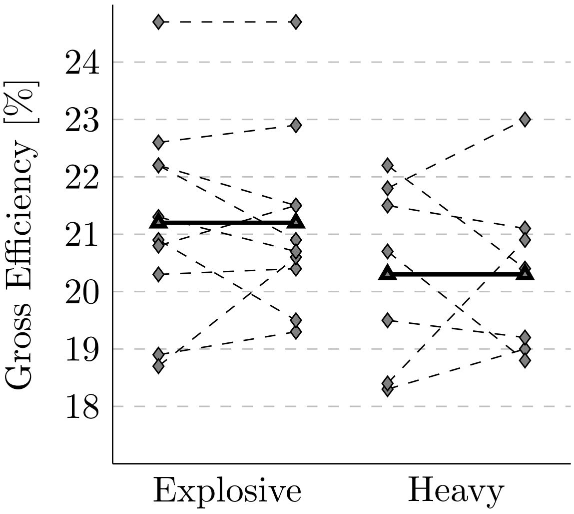

Figure 6.11.: Pre-post development of Gross Efficiency at 70% of FTP per group. Bold line represents group average.

Table 6.5.: Mean ± SD data of cycling economy test at 60% load from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Power (W)	167 ± 39	170 ± 38	1.5 ± 2.3
$\dot{V}O_2$ to weight (ml/kg/min)	30.1 ± 5.2	30.4 ± 5.4	1.3 ± 5.7
Heart Rate (BPM)	124 ± 12	122 ± 10	-1.7 ± 5.0
RER	0.91 ± 0.03	0.91 ± 0.08	0.6 ± 8.7
$\dot{V}O_2$ (l/min)	2.27 ± 0.44	2.22 ± 0.37	-1.9 ± 5.0
$\dot{V}CO_2$ (l/min)	2.07 ± 0.41	2.01 ± 0.27	-1.3 ± 10.3
Cycling Economy (GE, %)	20.7 ± 1.6	21.4 ± 1.8	3.6 ± 5.6

Heavy strength training group

	Pre	Post	% change
Power (W)	170 ± 27	172 ± 26	1.1 ± 1.4
$\dot{V}O_2$ to weight (ml/kg/min)	30.7 ± 3.8	31.5 ± 5.1	2.4 ± 7.5
Heart Rate (BPM)	119 ± 5	118 ± 8	0.0 ± 9.2
RER	0.94 ± 0.08	0.91 ± 0.06	-2.5 ± 7.1
$\dot{V}O_2$ (l/min)	2.43 ± 0.27	2.48 ± 0.36	2.1 ± 7.6
$\dot{V}CO_2$ (l/min)	2.28 ± 0.32	2.28 ± 0.43	-0.5 ± 8.5
Cycling Economy (GE, %)	19.6 ± 1.7	19.5 ± 1.4	-0.1 ± 8.1

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

Table 6.6.: Mean ± SD data of cycling economy test at 70% load from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Power (W)	192 ± 45	193 ± 45	0.9 ± 1.7
$\dot{V}O_2$ to weight (ml/kg/min)	33.4 ± 6	34.4 ± 6.6	2.9 ± 5.7
Heart rate (BPM)	132 ± 16	131 ± 11	0.3 ± 8.5
RER	0.92 ± 0.04	0.92 ± 0.07	-0.4 ± 7.2
$\dot{V}O_2$ (l/min)	2.53 ± 0.56	2.56 ± 0.55	1.3 ± 5.8
$\dot{V}CO_2$ (l/min)	2.34 ± 0.52	2.34 ± 0.37	1.2 ± 8.1
Cycling Economy (GE, %)	21.2 ± 1.8	21.2 ± 1.6	-0.1 ± 4.8

Heavy strength training group

	Pre	Post	% change
Power (W)	198 ± 29	201 ± 28	1.6 ± 1.5
$\dot{V}O_2$ to weight (ml/kg/min)	34.4 ± 4.2	35.4 ± 5.6	2.7 ± 7.6
Heart rate (BPM)	130 ± 7	127 ± 8	-1.4 ± 8.4
RER	0.92 ± 0.95 ± 0.06	0.93 ± 0.05	-1.9 ± 6.3
$\dot{V}O_2$ (l/min)	2.72 ± 0.30	2.79 ± 0.38	2.3 ± 7.7
$\dot{V}CO_2$ (l/min)	2.58 ± 0.36	2.60 ± 0.47	0.4 ± 8.2
Cycling Economy (GE, %)	20.3 ± 1.6	20.3 ± 1.5	0.2 ± 8.0

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

6.5.4. Anaerobic Capacity

Sprints

There were no significant differences for any measured variable in neither the seated or the standing sprints between the groups.

For the seated sprint the explosive strength training group showed a significant increase from pre to post intervention on all metrics; average power (P=0.004), average power to weight (P=0.02), peak power (P=0.002) and peak power to weight (P=0.001). The heavy strength training group showed a significant increase in average power (P=0.01) and average power to weight (P=0.01) only.

For the standing sprint the explosive strength training group showed a significant increase in all the variables; average power (P=0.04), average power to weight (P=0.001), peak power (P=0.02) and peak power to weight (P=0.01). The heavy strength training group showed no significant changes from pre to post intervention.

Figures 6.12 and 6.13 shows each participant's pre- to post development of average power to weight for the seated and standing sprint, respectively. Group-level data are given in tables 6.7 and 6.8, respectively.

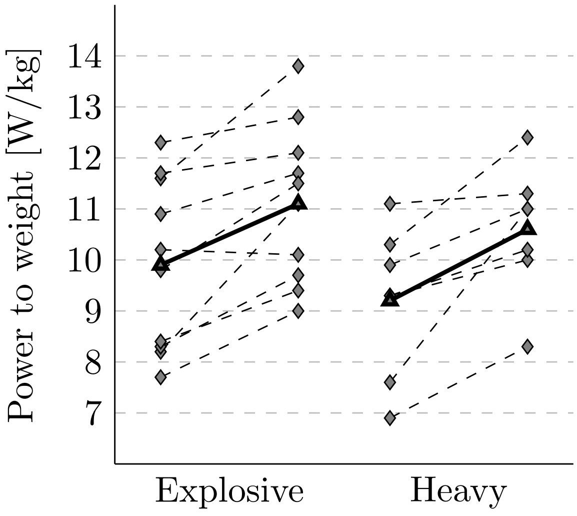

Figure 6.12.: Pre-post development of seated sprint average power to weight per group. Bold line represents group average.

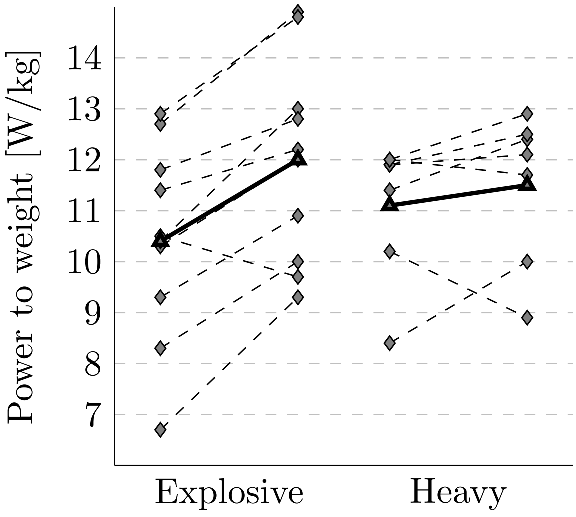

Figure 6.13.: Pre-post development of standing sprint average power to weight per group. Bold line represents group average.

Table 6.7.: Mean ± SD data of seated sprint from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Power (W)	746,4 ± 104,6	825,3 ± 95,1	11,3 ± 9,8*
Power to weight (W/kg)	9,9 ± 1,7	11, 1 ± 1,6	13,1 ± 10,5*
Power$_{peak}$ (W)	809,5 ± 98,1	855,1 ± 101,3	5,76 ± 4,3*
Power$_{peak}$ to weight (W/kg)	110,8 ± 1,7	11,5 ± 1,7	7,46 ± 4,9*

Heavy strength training group

	Pre	Post	% change
Power (W)	726,1 ± 93,3	836,9 ± 92,2	16,1 ± 12,8*
Power to weight (W/kg)	9,2 ± 1,5	10,6 ± 1,3	16,5 ± 14,1*
Power$_{peak}$ (W)	818,6 ± 100,1	869,6 ± 101,9	6,9 ± 11
Power$_{peak}$ to weight (W/kg)	10,4 ± 1,5	11,0 ± 1,4	7,5 ± 11,2

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

Table 6.8.: Mean ± SD data of standing sprint from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Power (W)	778,8 ± 91,1	883 ± 93,3	14,1 ± 12,1*
Power to weight (W/kg)	10,4 ± 1,9	12 ± 2,0	15,8 ± 12,1*
Power$_{peak}$ (W)	880,4 ± 100,6	932,0 ± 108,7	6,1 ± 6,9*
Power$_{peak}$ to weight (W/kg)	11,8 ± 2,1	12,6 ± 2,3	7,7 ± 7,9*

Heavy strength training group

	Pre	Post	% change
Power (W)	882,4 ± 117,7	905,5 ± 95,8	3,4 ± 10,73
Power to weight (W/kg)	11,1 ± 1,4	11,5 ± 1,5	3,8 ± 9,9
Power$_{peak}$ (W)	942,7 ± 140,5	961,4 ± 111,3	2,9 ± 11,0
Power$_{peak}$ to weight (W/kg)	11,9 ± 1,7	12,2 ± 1,7	2,8 ± 9,9

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

Wingate

There were no significant differences between the groups in the Wingate test. The average power to weight had a statistically significant increase (P=0,04) from pre to post test for the explosive strength training group. No significant changes were found within the heavy strength training group.

Figures 6.14 and 6.15 shows each participant's pre- to post development of average and peak power to weight for the Wingate test. Group-level data are given in table 6.9.

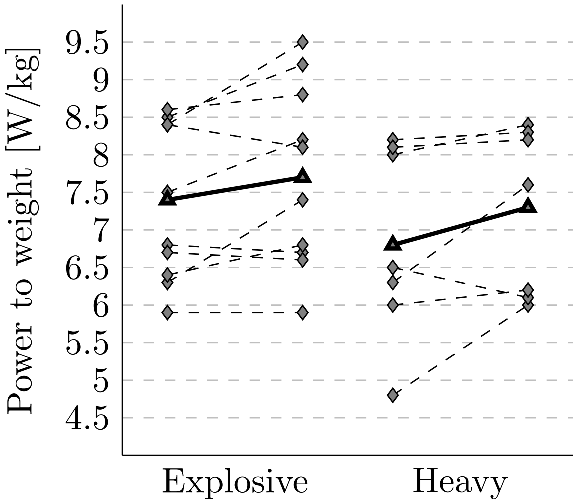

Figure 6.14.: Pre-post development of Wingate test average power to weight per group. Bold line represents group average.

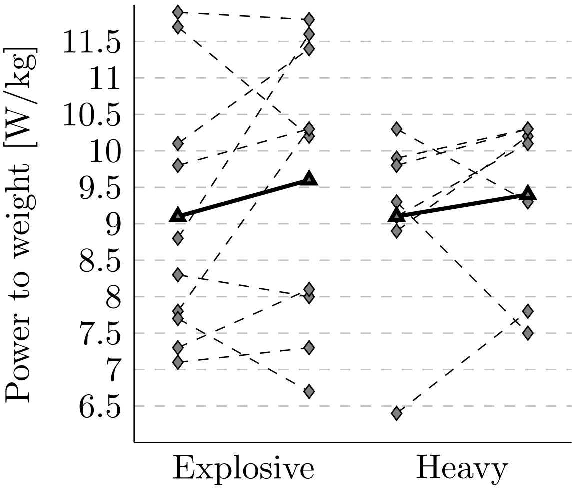

Figure 6.15.: Pre-post development of Wingate test peak power to weight per group. Bold line represents group average.

Table 6.9.: Mean ± SD data of Wingate test from pre- to post intervention test

Explosive strength training group

	Pre	Post	% change
Power (W)	552 ± 61	571 ± 68	3.4 ± 6.3
Power to weight (W/kg)	7.4 ± 1.1	7.7 ± 1.2	5.0 ± 7.0*
Power$_{peak}$ (W)	676 ± 86	709 ± 130	5.0 ± 15.3
Power$_{peak}$ to weight (W/kg)	9.1 ± 1.8	9.6 ± 1.9	6.5 ± 15.9

Heavy strength training group

	Pre	Post	% change
Power (W)	540 ± 88	570 ± 64	6.9 ± 12.4
Power to weight (W/kg)	6.8 ± 1.3	7.3 ± 1.1	7.2 ± 11.3
Power$_{peak}$ (W)	720 ± 110	738 ± 91	3.9 ± 14.5
Power$_{peak}$ to weight (W/kg)	9.1 ± 1.3	9.4 ± 1.2	3.9 ± 14.2

* indicates a significant difference from pre- to post test for this group on a $P < 0.05$ level.

7. Discussion

7.1. Body Composition

The fact that the pre-tests was conducted right after the christmas holiday, there was expected some changes in the body composition. Some of the participants had in advance reported a lower level of activity, and a higher than normal dietary intake. A precondition for this expectation is of course a normal dietary intake during the intervention period, and following the training program from the participants point of view. The intervention did not control for nutrition, but the training log confirms an adherence of over 85% to the training program. The observed decrease in body mass and BMI in the explosive strength training group could therefore be explained by a higher activity level of endurance training and some dietary changes compared to the weeks prior to the intervention.

The result did also show that none of the groups had an increase in body mass despite an increase in muscle strength and muscle mass. This is in line with other studies reporting the effect of adding strength training to the endurance training in cyclists (Aagaard et al., 2011; Hoff, Gran & Helgerud, 2002; Rønnestad et al., 2010; Rønnestad et al., 2014; Sunde et al., 2010; Vikmoen et al., 2015). This is also in line with the early findings of Hickson (1980) known as the interference effect; concurrent training compromises gains in muscle hypertrophy and strength which makes strength training beneficial for endurance performance.

Improvements of results given as a metric (power output and oxygen uptake) relative to the athlete's body mass can most probably be credited to reduction in body mass. Changes in body mass caused by the training intervention was not hypothesized prior to commencing the study, but the decrease in body mass can indeed have affected the power to (body) weight variables measured during the 20 minute all out test, the 5 second sprints and the Wingate test, as well as the oxygen uptake to weight used to quantify the $\dot{V}O_{2max}$ and performance $\dot{V}O_2$. Whether these alterations resulted from the endurance training, the strength training or a combination of both is hard to tell in our case. Including a sufficiently populous control group would have aided in determining this.

7.2. Strength Training

None of the participants had been doing strength exercises for the past six month prior to the study. A certain improvement was therefore expected for both of the strength training groups. An improvement in strength is expected to be about 1% for each strength training session when performing 1RM strength (Gjerset et al., 2015). According to Vikmoen et al. (2015), an increase in 1RM leg-strength is considered as an upper-range level when the increase is observed to be from 25-40% in studies combining endurance- and heavy strength training. Both of the groups reached this level except the toe raise exercise for the explosive strength training group. Despite a lack of studies in the explosive strength training field, and thereby some uncertainty in what level of increase to expect, it is surprisingly that the explosive strength training group had such a high increase. The lighter loads, the smaller increase in muscular strength. A strength increase of 3-15% of 1RM in squat and leg press is reported after strength training with no external load (Moss, Refsnes, Abildgaard, Nicolaysen & Jensen, 1997).

The heavy strength training group achieved the largest improvement in muscle strength, but some questions are still unanswered when the differences were not statistically significant between the groups. An improvement of almost 60% in the squat exercise in the current study is a remarkably high number. Other studies measuring the effect of strength training have scheduled two weeks of familiarization sessions prior to the intervention period (Aagaard et al., 2011). The purpose of such a familiarization period is to avoid that the learning effect experienced when embarking on a strength training program exaggerates the measured effect of strength training. It is also desirable that the participants learn proper lifting technique using lighter loads to reduce the risk of injuries. For instance, it is reasonable to believe that when a participant experience an increase well over 100 percent from the pre- to the post test, the participant didn't actually increase his muscle strength by 100 percent, but rather, his improvements in muscle strength and lifting technique in combination increased his lifting capacity by 100 percent.

The participants in the current study were encouraged to do a couple of familiarization sessions before the pre test, just to avoid such circumstances, but it was optional. A possible way to detect some potential stable numbers is to analyze the strength training log for the heavy strength training group. Five out of seven participants had a sufficiently useful log to use in such a calculation. When omitting the first 4 strength training sessions (about two weeks) from the calculation, the number in strength increase is 49.9 ±37.4% in the squat exercise. From pre to mid intervention the increase was 47.8 ±36.3%. From pre to post intervention the growth was at 66.8 ±35.4%. This means that the strength increase from mid to post intervention happened to be 12.8 %. The number corresponds with the theory of 1% strength increase each session when performing 1RM strength, and can tell us that the development of strength improvement experienced the biggest growth during the first third of the intervention period. This is in line with the early findings of Hickson (1980) who demonstrated that the capacity to develop strength leveled off after 7 weeks when he compared the strength training group to a concurrent endurance and strength training group. However, a calculation from the training log should not be given such merit because of the low number of participants (n = 5), and the study of Hickson (1980) is not directly comparable due to differences in experimental design. If the capacity to develop increased muscle strength does indeed decline after about 7 weeks, does not automatically say it's not valuable to follow a strength training program for more than 7 weeks. Later research by Rønnestad et al. (2010) demonstrated a good effect on strength capabilities when performing a strength maintenance session once a week during a competition period. Another recent study by Rønnestad, Hansen, Hollan et al. (2016) demonstrated reductions in strength capabilities adapted from a 25 week preparatory period when omitting the strength training the first 8 weeks of the competition season.

The science of concurrent training is complex and still holds many unanswered questions. Why the differences in strength between the groups were not significant in the current study remains somewhat unclear. However, from another point of view it is an interesting result. The participants in the explosive strength training group reported a low level of fatigue when performing the strength training. Further, they reported no sore legs after strength training when performing the threshold sessions on the bike.This is the opposite report compared to the heavy strength training group. The current explosive strength training concept with moderate resistance showed that a significant growth of muscle strength can be achieved without causing fatigue or need for longer recovery. With this in mind it should be good reasons for incorporating this type of strength training to the ongoing endurance training for this group of cyclists - given that performing explosive strength training results in a measurable improvement to cycling performance.

7.3. Physiological Performance Indicators

7.3.1. 20 minute all out performance

The lack of significant change in mean power output during the 20 minute all out test is in accordance with other studies reporting no effect of concurrent strength and endurance training on long term endurance performance (Bastiaans et al., 2001; Bishop et al., 1999; Jackson et al., 2007; Levin et al., 2009; Psilander et al., 2014). These studies is typical explosive type studies with light to medium load with high repetitions. Positive effects on long term performance is reported after heavy strength training (Aagaard et al., 2011; Rønnestad et al., 2010; Rønnestad et al., 2014; Vikmoen et al., 2015).

As described and displayed in the model shown in figure 2.1, the long term endurance performance (LTP) is first of all determined by performance $\dot{V}O_2$ and cycling economy. Vikmoen et al. (2015) reported an increased performance $\dot{V}O_2$ due to improved fractional utilization of $\dot{V}O_{2\text{max}}$. As described in the theory section, there is a linkage between the fractional utilization of $\dot{V}O_{2\text{max}}$ and adaptions in the muscles (Bassett and Howley (2000) after Holloszy and Coyle (1984)). Vikmoen (2015) related the improvement to increased muscle CSA of the quadriceps. In fact, the same heavy strength training regime, designed by Rønnestad and colleagues, was used in the study of Vikmoen et al. (2015) and in the current study. However, no improvements of fractional utilization of $\dot{V}O_{2max}$ was found for any of the intervention groups. When both groups improved the muscle strength, which probably means that muscle CSA was increased, other factors contributing to the long term cycling performance should explain this lack of improvement (e.g. efficiency).

Usually, a reduction in heart rate post-intervention can be a good indicator of improved performance. However, when the mean power output and the fractional utilization of $\dot{V}O_{2max}$ decreased, as well as no measured improvement of $\dot{V}O_{2max}$ in the heavy strength training group, we can not say that the lowered heart rate at post test was related to improved cycling performance. Because of this contradictory finding it is desirable to have a deeper look at the results for the heavy strength training group in the current study, and the result must be seen in context with the other measured variables and all the information we got. One example is the information about entering the post test fully recovered. During a long and dark and norwegian winter with a lot of indoor training it is tempting to join a long group ride prior to the test when the sun is shining and the roads are dry again. The feeling of illness some days before the test is not optimal either. And the psychological effect when a participant comes to the test and is delivering a sub-par performance will also have an impact on the test results.

When browsing the available literature it seems like the positive effects on the long term cycling performance is reported after 1) heavy strength training regimes 2) for well trained to elite cyclists 3) with a high load of endurance training and 4) lasting 10-12 weeks. A couple of these points could explain why the heavy strength training group in the current study did not show the expected improvements. The analysis of the training log confirms a huge gap in the amount of performed low intensity endurance training between the participants. A well-known principle in the literature of training and sport science is specificity; the importance of performing sufficient volume of training in the sport you are training for. As mentioned in the method section, the cyclists in the current study fulfilled Jeukendrup et al. (2000)'s description of a well trained cyclist according to training and race status, but not everyone fulfilled the criteria for the physiological variables like absolute and relative $w\dot{V}O_{2max}$ and $\dot{V}O_{2max}$. This variance in a combination with the low number of participants in the heavy strength training group could consequently influence the result.

Another aspect is the already mentioned reports about sore legs from the heavy strength training sessions. Participants from the heavy strength training group reported bad quality on the endurance threshold sessions on the bike, affected of the strength training. Hence, there are reasons to assume that a so called DOMS have affected both the bike sessions during the intervention as well as the result at the post test. This may indicate that the heavy strength training regime was not appropriate for this group of cyclists.

The increase in average power to weight (P=0.08) for the explosive strength training group can tell us that there is a potential effect on long term endurance performance of this strength training regime. The result is not in line with the older explosive type mentioned studies, and is therefore interesting. Maybe this could serve as a good contribution to the discussion about concurrent explosive strength training in this field.

7.3.2. $\dot{V}O_{2max}$

No significant change of $\dot{V}O_{2max}$ was measured for any of the intervention groups. This is in accordance with other studies assessing the effect of concurrent endurance and strength training for cyclists (Beattie et al., 2017; Bishop et al., 1999; Hickson et al., 1988; Jackson et al., 2007; Levin et al., 2009; Marcinik et al., 1991, 6; Rønnestad et al., 2010) meaning this result was expected. The endurance training program was designed as a so called MIT (moderate intensity training) program and thereby the focus was not in increasing the $\dot{V}O_{2max}$.

On the other hand, there was expected a better improvement for some of the participants, especially for those with the lowest fitness level at the pre test. The fact that the pretest was applied early in the winter training period may reinforce this assumption because after three moths with structured training, the curve should theoretically point upwards. A lack of experience with training on a power meter for these mentioned participants could potentially influence this result. Performing the threshold sessions with a too low intensity will not stimulate the $\dot{V}O_{2max}$, and training with an ambitious high power output will lead to early lactate production and force the participant to adjust the intensity which also will lead to a small stimulation of $\dot{V}O_{2max}$.

However, both of the groups measured an increase on group level (but not significant), and the explosive group showed the best development. The most interesting and inexplicable aspect is the measured $\dot{V}O_{2max}$ of the participant with the best fitness level and the most experience, who experienced a drastic decline from 71.9 (ml/kg/min) to 67.5 respectively. Questions regarding measurement error occurs, but this will be a speculation. The fact that the spring and pollen season was settling in in Norway during the post test may also have affected the result. Just having a bad day could be another reason. However, we are not talking about results on individual level in this type of research, but in this case this participant was standing out and greatly affected the group level result with this big drop in $\dot{V}O_{2max}$.

7.3.3. Cycling Economy

As mentioned above, we could not prove that growth in muscle strength and potentially increased muscle Cross-Sectional Area led to improved fractional utilization of $\dot{V}O_{2max}$, which Vikmoen et al. (2015) did measure in his study. Since Performance $\dot{V}O_2$ together with Cycling Economy (CE) is regarded as the key indicators determining the long term cycling performance (see figure 2.1), and the study failed to show improvements in both fractional utilization of $\dot{V}O_{2max}$ and long term cycling performance, a lack of improvement in CE should be expected. The lack of improved CE is in accordance with other studies assessing the effect of strength training on the cycling endurance performance (Aagaard et al., 2011; Beattie et al., 2017; Jackson et al., 2007; Rønnestad et al., 2010; Rønnestad et al., 2014).

However, the increase in cycling economy at 60% of FTP in the explosive strength training group is in some ways interesting because of the significance level of (P=0.08), and the fact that this group measured a higher level of CE than the heavy strength training group. Horowitz, Sidossis and Coyle (1994) have shown that cyclists with a high gross efficiency (21,9%) were able to sustain a significantly higher power output (27W) during a 1-hour time trial performance than a group with a lower gross efficiency (20,4%). In the current study the explosive group increased the cycling economy from 20.7 to 21.4% at 60% power output during the intervention, which is regarded as a high gross efficiency. In contrast, the heavy strength training group measured respectively 19.6% at pre and 19.5% at post test. On the other hand, this positive result was not observed when measuring CE at 70% of FTP or during the 20 minute all out test, and then this finding does not provide significant merit.

The literature on the effect of strength training on cycling economy is contradictory. It seems to be no consensus in whether it is the cyclists with the high or low performance level who achieved improved cycling economy. The type of strength training may also influence the result. Loveless, Weber, Haseler and Schneider (2005) found increased cycling economy in untrained men after maximal strength training, while Aagaard et al. (2011) did not find this increase in top level cyclists. However, improvements in long term cycling performance was found, and one of the underlying factors was improved RFD. Another study of Sunde et al. (2010) related the improved cycling economy to improved RFD as well. As we recall from the theory section we can draw some parallels between explosive strength and RFD. Even if RFD was not measured in the current study, there could potentially be a context between the result of CE and improved RFD in the explosive strength training group.

A conversion of type IIX into IIAX or IIA is observed during strength training. The conversion will possibly happen toward type I fibers when adding endurance training to the strength training (Gjerset et al., 2015). Horowitz et al. (1994) demonstrated that the cyclist with the best cycling economy had a greater percentage of type I muscle fibers in the *vastus lateralis* when comparing elite cyclists. The pattern of motor unit recruitment during movement was suspected to have a significant effect on work economy. Vikmoen et al. (2015) related the improvement in a 40 minute all out test to improved cycling economy. The cyclists in that study was probably able to take advantage of the more economical type I fiber at higher power outputs. Other mechanisms behind the improved CE was increased muscle strength and muscle CSA as well as a fiber type shift from type IIAX-IIX fibres to the more economical type IIA.

The mechanisms of strength training affecting CE are complex, and challenging to comprehend. We can establish that CE is linked to adaptions in the muscles, and that strength training can have a positive effect. The explosive group did increase the muscle strength and the muscle mass, but the positive result (tendency) in CE did not occur during higher power outputs. However, it is reasonable to believe that some of the same mechanisms behind the improved cycling economy after the heavy strength training of Vikmoen et al. (2015) occurred after the explosive strength training in the current study.

Why the improvement wasn't better may be explained by a couple of factors. First of all, the participants had to concentrate themselves at this test segment, especially at the post test. As mentioned in method section, the participants was instructed to use the similar power output and cadence during post test as pre test at this test segment. Nervousness could be another factor affecting the result because this measurement came so early in the test. And lastly, some of the participant altered their pedal revolution during the training period and came back at post test commanded to perform an unrealistic pedal revolution compared to their daily training. When the difference ranged from 70 to 90-100 RPM, this would probably affect the efficiency.

7.3.4. Anaerobic Capacity

The anaerobic capacity assessed by the Wingate test, the 5-second sprints and the $\text{w}\dot{\text{V}}\text{O}_{2\text{max}}$ are as described in the text and illustrated in the performance model in figure 2.1 determinants of the cyclist's short term performance (STP), and reflects the cyclist's ability to produce high power outputs in brief periods of time.

Power output at maximal oxygen uptake ($\text{w}\dot{\text{V}}\text{O}_{2\text{max}}$)

Since $\text{w}\dot{\text{V}}\text{O}_{2\text{max}}$ is a composite of $\dot{\text{V}}\text{O}_{2\text{max}}$, CE and anaerobic capacity, improvements in $\text{w}\dot{\text{V}}\text{O}_{2\text{max}}$ should result from an improvement of one or more of these factors. As we have already determined, no improvements in $\text{w}\dot{\text{V}}\text{O}_{2\text{max}}$ or CE at higher power outputs was observed, which can also explain the lack of improvements of ($\text{w}\dot{\text{V}}\text{O}_{2\text{max}}$). The findings from previously published studies on the effect of strength training on this performance indicator are contradicting. Rønnestad et al. (2011a) found improvements after a similar heavy strength training regime, while Vikmoen et al. (2015) (also using similar strength training regime) did not observe this improvement. This was an unexpected outcome since they reported improvements in CE. Here they were assuming that the test maybe wasn't sufficiently sensitive, but could not find any evidence to claim that.

The already mentioned studies focusing on explosive type strength training did not find improvements in $w\dot{V}O_{2\max}$ (Bastiaans et al., 2001; Levin et al., 2009), but the methodology makes it difficult to relate the findings in the current study to these earlier activities. The reason for lack of improvements for both of the groups is hard to determine, but it is perhaps a combination of many of the above mentioned factors discussed in section 7.2. Another reason could be the mental part of the test. It requires a strong mental attitude to stay at the redline for the full final minute required to successfully complete this test segment, especially with the knowledge of what's to come later in the test. Experience is another keyword. Many of the participants in these groups had little experience conducting such a test segment, and the whole test protocol itself was strenuous effort for everyone, regardless of experience.

Wingate

The explosive strength training group experienced a significant increase in average power to weight during the Wingate test. The fact that the explosive group also had a significant decrease in body mass and BMI might partially explain this finding. The result corresponds to the study of Bastiaans et al. (2001) who showed that explosive type strength training was beneficial to the short term performance because the control group had e decline in the Wingate test while the strength training group had not. Sadly we had no control group and can not say with certainty that this happened in the current study.

The lack of improvement in Wingate average power in the heavy strength training group is in accordance with Rønnestad et al. (2010), who explain that strength training in general does not have a considerable effect on the glycolytic anaerobic energy system, which again is the key contributor of energy availability during the 30 second maximum effort that the Wingate test represents.

The picture appears a bit different when looking at the peak power output measured during the Wingate test, which does not rely on the ability to supply anaerobic energy for the full duration of the test. Studies conducted by Rønnestad et al. (2010) and Vikmoen et al. (2015) found significant improvements in peak power output during a Wingate test after having well-trained male and female cyclists perform a heavy strength training program. Increased muscle Cross-Sectional Area (CSA) and leg strength was given credit for this improvement. Although there was not found significant improvements in peak power variables in the current study, these metrics are sufficiently similar to the peak power variables in the sprinting tests. The Wingate test was the last test segment in the protocol while the sprints came early. Thus, the result of the Wingate test is most likely affected by this factor since the participants' ability to reach their maximum power output was limited due to exhaustion from previous test segments.

Sprinting ability

Both of the strength training groups had some commonalities in which they measured improvements in average power and average power to weight in the seated sprint. As we recall from section 6.3, the groups also had a large increase in lower limb muscle strength in common. An important factor for determining anaerobic capacity is muscle mass (Vikmoen et al. (2015) after Bangsbo (1993)). Rønnestad et al. (2010) related the improved peak power output of 5 seconds to increased thigh muscle CSA. Thus, an explanation for the improvements in the seated sprint is probably increased muscle and leg strength, and muscle CSA. When the explosive group increased all the sprint variables like standing sprints and peak power variables as well, it may be related to changes in body composition.

It is likely to say that explosive strength training improved explosive strength qualities and neuromuscular force production, like the ability of the muscle to develop high force at high velocities. According to Sale (1988) neural adaptions after resistance training can improve maximal force production and RFD. Increased RFD could serve as an explanation behind the sprint improvements in the current study, as well as the improvement in the Wingate test. No measurements of RFD was conducted, however improvements in RFD is found after concurrent heavy strength training in well trained cyclists (Aagaard et al., 2011; Sunde et al., 2010) as discussed in section 7.3.3.

According to Rønnestad and Mujika (2013) a conversion of fast-twitch type IIX fibers into type IIA fibers can explain the muscle physiology for improved endurance performance after heavy strength training. Browsing through available publications, there are indications giving reason to believe that the same conversion is happening through explosive strength training. And since the anaerobic energy systems are largely associated with type II muscle fibers (Gjerset et al., 2015), the increase in average and peak power in all the measured sprint variables in the explosive strength training group may be explained by increases in the fast-twitch muscle fiber types. When adding endurance training to the strength training, the conversion leads towards the type IIA fibers which have the potential to increase a greater force production, and improves the cycling endurance performance. Driss and Vandewalle (2013) reported a significant correlation between the percentage of the fast-twitch muscle fibers in the *vastus lateralis* and peak power in a Wingate test. As mentioned above, the peak power variables in Wingate and sprint are sufficiently similar, and will probably share some of the mechanisms behind the improvements.

With this literature available, it should also serve as a clear indication that explosive strength training might be beneficial to cycling anaerobic capacity.

7.4. Methodology

Two important factors make up the primary limitations of the study. The first methodological limitation of the study was the lack of a proper control group, or the fact that the number of participants in the control group was too minuscule to be included in the analysis. The study involved a small control group where the participants performed endurance training without added strength training, but because of the small number of participants the data from this group is excluded from the results. In this study we wanted to compare two different strength training regimes, but in hindsight we should have given the control group more attention and made it proper from the beginning. It would then have been possible to evaluate the explosive strength training more thoroughly.

The other important methodological limitation stems from giving insufficient attention to observing, and if necessary correcting the participants when performing strength training throughout the intervention period (beyond the instruction sessions during the first week of the intervention). Studies showing good results after a strength training intervention seems to have a high degree of follow-up. There was from the beginning of the project made a strategy according to follow ups in cooperation with a bachelor student, but when the student left the project, digital solutions were implemented. Many of the participants did send videos from the strength training sessions, but it is still a low degree of validity.

There are some limitations caused by the timing of the intervention. The intervention took place during the norwegian winter, and caused illness leading to a lower adherence in the training program for some of the participants. In some cases the illness caused drop outs. The fact that the pre tests was done right after the christmas holiday was not optimal either, but when the intervention was supposed to last in 12 weeks after the testing week there wasn't actually many other alternatives.

The best training method to improve the endurance cycling performance is obviously endurance training (Mujika, Rønnestad & Martin, 2016). When analysing the participants training diaries there seem to be a big difference between the total number of endurance training between some of the participants as already explained in the result section. Even if the adherence was high to both the strength training and the two specific threshold sessions on the bike, this study wanted to evaluate the training effect on the cycling endurance performance. The study searched for well trained cyclists and there was an expectation that a well trained cyclist would perform a certain number of zone 1-training in addition to the prescribed training program. A couple of the participants performed mostly the two threshold sessions and the two strength training sessions only, but since they belonged to both of the groups they were not excluded.

Some studies report that the participants did not get any information about the measurement parameters, and in some studies they did, like in the current study. The investigator experienced a negative outcome of this at the post test when some of the participants did not perform as expected, had heavy legs etc. When the participants observed a lower number of power output than usual during the 20 minute all-out test, but experienced the same training stress on the body as when performing a higher power output, a need of motivating them to fulfill the test arose. Hence, a negative psychological effect of observing the measurements.

The participants performed the endurance test on a normal road bike on a trainer simulating a steady incline, which meant that they had to choose and shift gears at their own will. This could represent a challenge when they were tasked to gradually increase their efforts up towards complete exhaustion during the stepped $\dot{V}O_{2max}$ test, which does require some experience in order to reach one's full potential. Alternatively, one could have switched the trainer to ergometer mode during this test segment, in which the trainer provides resistance equaling a given power output level rather than a given incline, forcing the athlete to produce neither less or more than the given power output. The disadvantage of using ergometer mode is that the final level would be limited by the (estimated) functional threshold power entered before starting the test, which may not correlate well with the actual $w\dot{V}O_{2max}$ (and indirectly the $\dot{V}O_{2max}$) from one athlete to another.

Despite no measurements of lactate during this test protocol, most of the participants had experience with training on a power meter, and had a relative high degree of control of the intensity during watt zones. As mentioned earlier, many of the participants joined the Zwift community and could perform the threshold sessions on a smart trainer which contributed to a high degree of validity. However, every participant logged their time in the respective training zones through the digital solution of the training log.

Some training interventions have conducted a couple of tapering weeks prior to the post test. The fact that a high number of the participants in the heavy strength training group reported heavy legs or having a bad day during the post test, a recovery period to adapt the strength training could potentially given another result. In fact, one of the participants came back for performing another post test to determine if the bad measurement was due to having a bad day or not. The test was interrupted when he got the same negative results. There should be no doubt then, if the result was affected by a bad day or that the participant actually performed at a lower level after 12 weeks. This could most likely be related to other participants performing sub par.

Mid-test

Halfway throughout the intervention period (ie. after six weeks of training), the participants performed a simplified test protocol that did not contain the 20 minute all out test, but otherwise identical to the pre- and post test protocol. The intention was to use data analyzing the participants' development from the pre-test to the mid-test as basis for another study running in parallel, focused primarily on the strength training itself, and to a lesser degree on its significance for improving cycling performance (hence the simplified endurance test). This parallel study was canceled, and due to the lack of a 20 minute all out test, which produces some of the most important metrics for our study, it was decided that it was not worth the effort to include analysis of the results of the mid-test.

8. Conclusion

The main goal for this strength training intervention was to investigate whether explosive strength training could provide similar improvements of cycling endurance performance as heavy strength training has been proven to give for well-trained cyclists. Due to the potential risks and disadvantages associated with heavy strength training, special attention was given to examining the effect of explosive strength training since the scientific results concerning explosive strength training defined in the manner used in this study are few and far between.

1. In accordance with hypothesis 1, the explosive strength training concept did not benefit the long term cycling endurance performance.
2. The main finding was that hypothesis 2 was partially supported, as the explosive strength training group achieved improvements in short-term cycling performance (STP). The positive effects was related to improved anaerobic capacity. Potential mechanisms was probably increased muscle strength and muscle CSA, increases in fast twitch muscle fibers, and a conversion from type IIX towards IIA fibers, improved neuromuscular force production like increased RFD. At the same time it should be noted, that since no significant differences was measured between the groups, we cannot say for a fact that the explosive group experienced more improvement than the heavy group.
3. And finally, our findings does not support the hypothesis 3 because the heavy strength training group did not achieve the expected improvements as found in earlier studies. A correlation with the result achieved by the cited studies could not be established.

8.1. Practical Applications

In this study we wanted to determine if it was possible to alter the way the strength training is performed, while still receiving the desired benefits. The study demonstrated that both of the strength training groups increased their muscle strength to an upper range level. Further, this study showed that the heavy strength training concept which have resulted in improved cycling performance in well trained to elite cyclists, was not beneficial for this group of cyclists. Muscular fatigue and DOMS are factors important to understand this result, while lack of proper follow-up during the strength training sessions, and lack of a proper control group was limiting factors to this study.

The tendencies towards significant improvement in average power to weight in the

20-minute all out test and CE at 60% power output in the explosive strength training group is regarded interesting because it may tell us about a potential effect. The main finding is the improved anaerobic capacity through assessments in variables for short term performance in this group. The explosive strength training gave some of the desired benefits a cyclist need to perform at his or her highest level. This strength training concept showed the strongest effects on anaerobic capacity, however, the overall cycling performance depends on energy availability from both aerobic and anaerobic sources. A cyclists will not get the chance to utilize his or her anaerobic capacity unless the aerobic capacity has put them where the battle for positions happens in the first place - which is typically during the latter half of a competition.

Even though the long term endurance performance did not improve significantly, strength training can prevent injuries, and a strong athlete is usually seen as a highly performing one. Considering age, strength training will probably be more important after passing 30 years of age due to the fact that sprint and endurance performance has been shown to gradually decline over the years. Coaches should always follow the principle of individually adapted training plans and observe the athlete's response to the training when designing a training program. Genetic and anthropometric factors can influence the adaptions of strength training in an undesirable way. The current strength level of every athlete should be targeted, and exercise, load, velocity, volume and frequency should be customized in accordance. Time can for certain athletes be a crucial factor and be given attention when designing training programs, especially for masters athletes. The fact that the outcome of a cycling race depends on both physiological, bio-mechanical, and tactical factors, it is not necessary the cyclists scoring highest on purely physiological test criteria who will climb to the top of the podium in the end.

Endurance training on one hand and strength training on the other are representing extreme forms of exercise, and combining them makes it even more extreme. ”The simultanous developement of muscular endurance and strength/power arguably represents the highest complexity in exercise prescription” (Coffey & Hawley, 2016). There are still many unanswered questions and mechanisms not completely understood. There are infinite number of ways to combine the various components of a strength training program. Therefore, it is impossible to find the optimal strength training program for a given purpose (Gjerset et al., 2015). Future research should investigate the effect of explosive strength training with a load of around 60% of 1RM, or a combination with plyometrics would have been interesting. Another interesting combination is running. The fact that running is time-saving, aerobic by nature and also have a positive effect on bone density, it can make up partially for the strength training.

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Appendix A.: The Borg Scale

Table A.1.: Borg scale of rated perceived exertion (RPE)

Level	Perceived Exertion
0	Nothing at all
0.5	Extremely weak
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Near maximum effort
·	Maximum effort

The RPE scale shown in table A.1 is based on the original CR10 scale defined by Borg (1982).

Appendix B.: Endurance Training Program

Utholdenhetsøkter med høyere intensitet på sykkel

- 2(/3) økter i uka

Her er en plan for de to hardøktene i uka som deltagerne skal forholde seg til i de 12 ukene studien varer. Som vi har beskrevet tidligere, så er det viktigste at deltagerne har lik tid i de ulike intensitetssonene. Om man kjører ei terskeløkt på for eksempel 4x15 eller 5x10 er ikke så nøye. Vi vet at mange av deltagerne går på gruppetimer med spinning. Prøv så godt det lar seg gjøre å justere slik at total dragtid blir så likt programmet som mulig.

Programmet har hovedvekt på tradisjonell "Sone 3-trening" med innslag av økter i intensitetssone 4. En god hovedregel er at hver tredje treningsøkt kan være med høyere intensitet, men man må tilpasse programmet til sin egen hverdag.

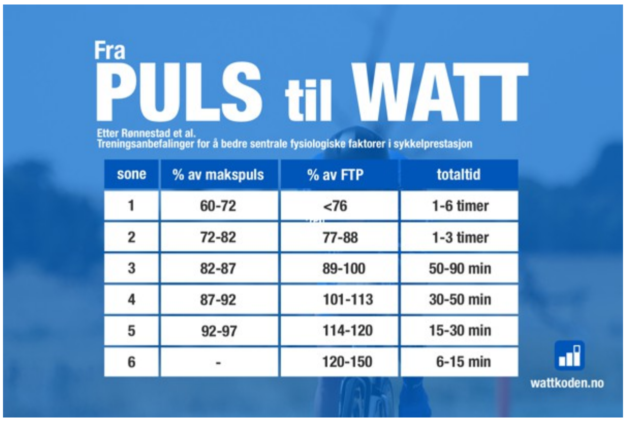
Wattstyrt trening vs. hjertefrekvens
FTP er en forkortelse for Functional Treshold Power, også kalt terskelwatt. Enkelt forklart er dette det punktet da kroppen forbruker like mye melkesyre som den produserer, den maksimale belastningen som du normalt kan holde en time. Dette er den tradisjonolle forklaringen og vi forholder oss til dette da FTP kan brukes som pekepinn når man kjører intervaller med wattbasert intensitetsstyring.

I testrapporten får du tallet på FTP´en du fikk under testen, men det er ikke sikkert den stemmer overens med sykkelrulla eller spinningsykkelen du bruker. Derfor er det lurt å enten ta en egen FTP-test på utstyret du bruker, eller justere deg opp eller ned.

Dersom du ikke har tilgang til wattbasert intensitetsstyring bruker du din funksjonelle terskel hjertefrekvens (FTHF, også kalt terskelpuls). Den snittpuslen du hadde under FTP-testen er en god pekepinn på hva som kan være din terskelpuls. Det viser seg at for noen er det riktigere å trekke 5% fra denne pulsen.

Når man kjører terskelintervaller, så skal intervallene være jevne og man er rimelig "ferdig" når siste intervall er kjørt. Imidlertid er det sånn at siden pulsen bruker litt tid på å stabilisere seg, så kan det spesielt på korte drag være vanskeligere å styre intensiteten etter pulsen. Det kan være lett å holde for høy intensitet tidlig i økta, man blir sur i muskulaturen og klarer ikke opprettholde den jevne belastningen. En god regel er å ikke være for ivrig de første minuttene av hvert drag.

Bildet nedenfor er lånt fra Wattkoden.no som viser forholdet mellom puls (Olympiatoppens intensitetssoner) og prosent av funksjonell terskelwatt.



Fra
PULS til WATT
Etter Rønnestad et al.
Treningsanbefalinger for å bedre sentrale fysiologiske faktorer i sykkelprestasjon

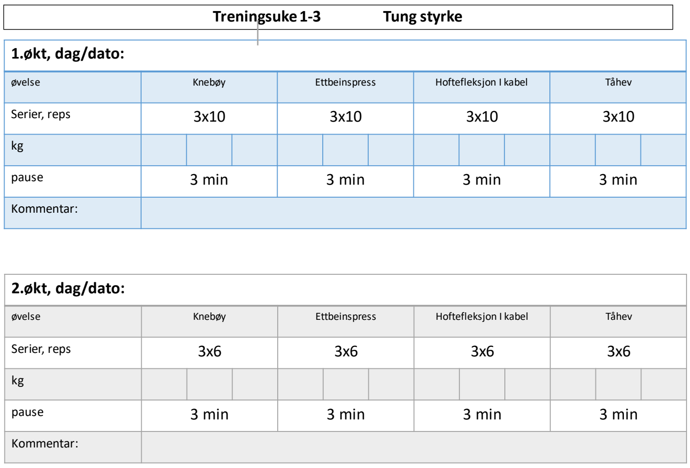
sone	% av makspuls	% av FTP	totaltid
1	60-72	<76	1-6 timer
2	72-82	77-88	1-3 timer
3	82-87	89-100	50-90 min
4	87-92	101-113	30-50 min
5	92-97	114-120	15-30 min
6	-	120-150	6-15 min

Som nevnt innledningsvis, er tanken bak programmet en stor hovedvekt på "sone 3-trening". Her tenker vi lavterskeløkter med lengre dragtid, og høyterskeløkter med kortere dragtid der pulsen gradvis vil bevege seg mot sone 4 for hvert drag. Disse øktene vil bygge kjørestyrke. Programmet følger kalenderukene.

	Utholdenhet med høyere intensitet dag 1			**Utholdenhet med høyere intensitet dag 2**			**Utholdenhet med høyere intensitet dag 3**		
Uke	**Øktnr**	**Kort beskrivelse**	**Total dragtid i min**	**Øktnr**	**Kort beskrivelse**	**Total dragtid i min**	**Øktnr**	**Kort beskrivelse**	**Total dragtid i min**
2	-	Test	-	1	Valgfri	-	-	-	-
3	2	Kontrolløkt etter FTP-test: 5x10. 3 min pause.	50	5	Pyramideintervall: (5-6-7-8-7-6-5) @ 100-105% av FTP. 3 min pause.	44	-	-	-
4	1	Lavterskel/sweetspot: 3x20 @90% av FTP. 3 min pause. Spin up, 20-30 sekunder hvert 6 min	60	7	6X6 @105% av FTP. 3 min pause.	36	-	-	-
5	6	Sweetspot-økt med pyramideintervall: (5-10-15-15-10-5) @ 90% av FTP. 2 min pause.	60	4	3x15 min Terskel "criss cross". 3-4 min pause.	45	8	5x4 min sone 4, 3 min pause.	20
6	1	Distanseøkt 45 min lavterskel (88-92% FTP). Spin-ups på opptil 20-sek. hvert 8. min.	45	9	Terskel+ økt: 5-20-20-5 min @ 106-100% av FTP. 3 min pause	50	-	-	-
7	1	Lavterskel 4x15 @ 90-95% av FTP. 3-4 min pause		-	Test	-	-	-	-
8	2	Kontrolløkt etter FTP-test: 5x10. 3-4 min pause.	50	10	VO2max-økt: 8x4 min, 3 min pause	32	-	-	-
9	11	3x20 MIKS. 95-100%. 3 min pause.	60	15	Sweetspot/lavterskel: 5x8 @90%. 3 min pause. Spin ups på opptil 20 sek halvveis i hvert drag.	40	-	-	-
10	13	5x12 "criss cross". 3 min pause	60	5	Pyramideintervall: (5-6-7-8-7-6-5) @ 100-105% av FTP. 3 min pause.	44		-	-
11	12	15x3 min @95-105%. 1 min pause.	45	1	Lavterskel 3x15 @ 90% av FTP. 3 min pause.	45		5x4 min sone 4, 3 min pause.	20
12	1	Distanseøkt 45 min lavterskel (88-92% FTP). Spin-ups på opptil 20-sek. hvert 8. min.	45	7	6X6 @105% av FTP. 3 min pause.	36			
13	11	3x20 MIKS. 95-100%. 3 min pause.	60	3	5x10 over /under FTP. 4 min pause.	50			
14	9	Terskel+ økt: 5-20-20-5 min @ 106-100% av FTP. 3 min pause	50		Test/økt nr 14				
15	2	Kontrolløkt etter FTP-test: 5x10. 3-4 min pause.	50		Test/økt nr 14				

Øktnummer	Beskrivelse
1	Lavterskeløkter er typisk 3x20 min, 4x15 min, eller distanseøkt på 45-60 min. Man trekker ifra omtrent 5-6% av FTP. Øktene er viktige for å legge en god "base". Ofte i disse øktene kan det legges inn korte ”spinn-ups” eller drag/spurter på opptil 20 sekunder.)
2	**5x10 minutt, 3-4 min pause (95-100% av FTP) - fin å kjøre som kontrolløkt etter FTP-test** Klarer du økta greit kan det være at FTP er satt for lavt, juster max 5 watt opp/ned. DET ER MYE BEDRE Å VÆRE PÅ DEN LAVE SIDEN ENN PÅ DEN TØFFE TRENINGSMESSIG!
3	**Tøff 5x10 , 4 min pause (5 min under FTP ca 98% og 5 min over FTP ca 102% på alle drag)** 5x10 minutter med 4 min. pause. De første 5 minuttene på hvert drag skal være litt under FTP, de siste 5 minuttene litt over.
4	**Terskel "crisscross" 3x15 / 4x15 min, 3-4 min pause** Terskeløkt som er stabil med 3 eller 4 drag av 15 min. De første 10 minuttene jevnt på ca 95%, deretter de siste 5 på ca 105% av FTP.
5	**Pyramide Høy (5-6-7-8-7-6-5) 105%-100% av FTP, 3 min pause.** De korteste dragene på høyest intensitet og motsatt. Tøff økt. Total dragtid er 44 min.
6	**Sweetspot-økt med pyramideintervall** (5-10-15-15-10-5 minutter) 1-2 min pause mellom dragene. Typisk 90% av FTP
7	**Terskel+ økt: 6x6 min, 3 min pause, (105% FTP)** Den er litt over terskelsone, men litt lav for å kalle det VO2max-sone på watt, puls vil helt klart være der oppe og du vil stimulere VO2max.
8	**5X4 min "sone 4".** Første drag kan brukes til å finne riktig belastning. Kan også legge inn et halvhardt drag i oppvarminga og kjenne på dagsform. Kontrollert start og heller øke utover i økta.
9	**Terskel+ økt: 5-20-20-5 min, 3 min pause** Morsom variasjonsøkt, som kan være tøff. Første 5 min: litt over terskel (ca. 105%), 20 min: litt under (ca. 95%), så siste 5 min på ca 105%. Spinn-ups på 20min drag i sweet spot (10 sek. ca 150%)
10	**VO2max, 8x4 min, 3 min pause** Tøff økt der intensiteten ligger mellom 105%-120% av FTP. Start kontrollert og juster deg ned ved behov.
11	**Terskel + økt: 3x 20 min MIKS, 3 min pause** Intervall 1: 1x20 @95% Intervall 2: pyramide; 1-2-3-4-4-3-2-1 @100-102%. Pause: 1 min. Intervall 3: 4x5 min @ 98-100%. Pause: 2 min.
12	**15x3 (95-105%), 1 min pause mellom hver 3-minutter** 5x3 @ 95% 5x3 @ 100% 5x3 @ 105%
13	**Criss Cross 5x12; 2min under - 2 min over. 3 min pause** De første 2 min kjøres på 90% av FTP, de 2 neste på 105%, så tilbake til 90% osv.
14	**Terskel + pyramide: 3-5-7-9-7-5-3 på FTP/100%, 3 min pause**
15	**Lavterskel/sweet spot: 5x8 min @ 90 % av FTP. 3 min pause.** Halvveis i hvert drag legges det inn en lett spin up med høyere kadens på opptil 20 sek. Belastningen skal være lik, målet er å fa litt fart i beina her.

Appendix C.: Strength Training Log



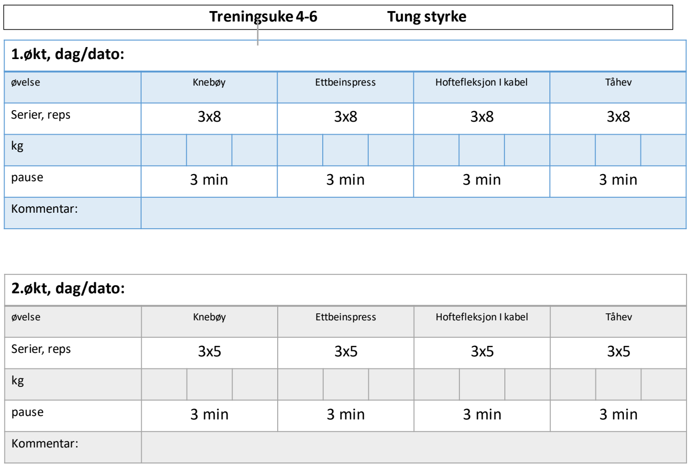
Treningsuke 1-3 **Tung styrke**

1.økt, dag/dato:

øvelse	Knebøy	Ettbeinspress	Hoftefleksjon I kabel	Tåhev
Serier, reps	3x10	3x10	3x10	3x10
kg				
pause	3 min	3 min	3 min	3 min
Kommentar:				

2.økt, dag/dato:

øvelse	Knebøy	Ettbeinspress	Hoftefleksjon I kabel	Tåhev
Serier, reps	3x6	3x6	3x6	3x6
kg				
pause	3 min	3 min	3 min	3 min
Kommentar:				



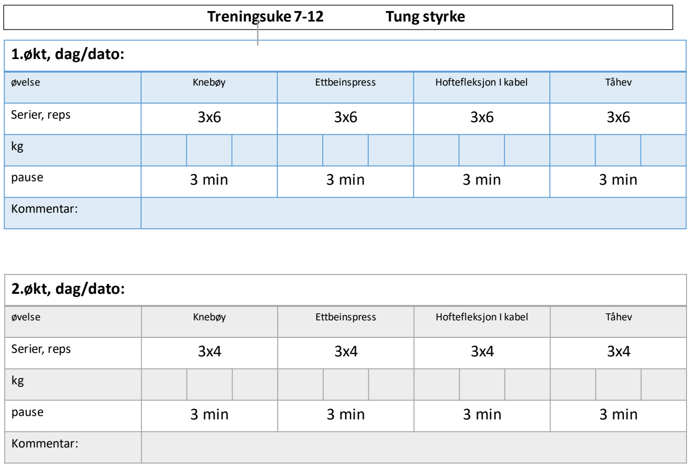
Treningsuke 4-6 **Tung styrke**

1.økt, dag/dato:

øvelse	Knebøy	Ettbeinspress	Hoftefleksjon I kabel	Tåhev
Serier, reps	3x8	3x8	3x8	3x8
kg				
pause	3 min	3 min	3 min	3 min
Kommentar:				

2.økt, dag/dato:

øvelse	Knebøy	Ettbeinspress	Hoftefleksjon I kabel	Tåhev
Serier, reps	3x5	3x5	3x5	3x5
kg				
pause	3 min	3 min	3 min	3 min
Kommentar:				



Treningsuke 7-12 **Tung styrke**

1.økt, dag/dato:

øvelse	Knebøy	Ettbeinspress	Hoftefleksjon I kabel	Tåhev
Serier, reps	3x6	3x6	3x6	3x6
kg				
pause	3 min	3 min	3 min	3 min
Kommentar:				

2.økt, dag/dato:

øvelse	Knebøy	Ettbeinspress	Hoftefleksjon I kabel	Tåhev
Serier, reps	3x4	3x4	3x4	3x4
kg				
pause	3 min	3 min	3 min	3 min
Kommentar:				

Appendix D.: Training Log

		Intensitetssone kondisjon [tt:mm]								Styrke				
Dato	Dag	Aktivitet	I1 (<76%FTP) (60-72% av maks HR)	I2 (77-88%FTP) (72-82% av maks HR)	I3 (89-100%FTP) (82-87% av maks HR)	I4 (101-113%FTP) (87-92% av maks HR)	I5 (114-120%FTP) (92-97% av maks HR)	Sum kondisjon Per økt	Per uke	Type	Tid	Sum Per uke	Dagsform Over/under gjennomsnittet?	Kommentar
10/30/2018	Tuesday	Sykkel inne	00:50					00:50					Over gjennomsnittet	Restitusjonsøkt
10/31/2018	Wednesday	Sykkel inne	00:30	00:10	00:10	00:30		01:20					Over gjennomsnittet	6 x 5 min I4 intervaller
11/01/2018	Thursday	Løping	01:00	01:00				02:00					Under gjennomsnittet	
11/02/2018	Friday	Langrenn	01:30	00:20	00:40			02:30					Over gjennomsnittet	
11/03/2018	Saturday	Styrke						00:00		maks	01:00		Under gjennomsnittet	Styrkeøkt 3x10. Knebøy 100 kg, Tåhev 115 kg, Hoftefleksjon 20 kg, Ettbeinspress 90 kg
11/04/2018	Sunday	Svømming	01:00					01:00	07:40			01:00	Under gjennomsnittet	
01/07/2019	Monday													
01/07/2019	Monday													
01/08/2019	Tuesday													
01/08/2019	Tuesday													
01/09/2019	Wednesday													
01/09/2019	Wednesday													
01/10/2019	Thursday													
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Appendix E.: Informed Consent

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *Styrketrening for syklister*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

☐ å delta i *eksperimentet*

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet, ca. november 2019

(Signert av prosjektdeltaker, dato)