

**Tina Bøgseth**

**The influence of training status on the fatigue threshold  
and performance during high intensity exercise.**

Master thesis in Human Movement Science

Trondheim, June 2015

Norwegian University of Science and technology

Faculty of Medicine

Department of Neuroscience (INM)

## Abstract

The influence of training status on the fatigue threshold and performance during high intensity exercise were studied in six endurance trained cyclists and seven recreationally students during 1 min anaerobic TT and 10 min aerobic TT. The peripheral fatigue was expressed as reduction in the potentiated single quadriceps twitch force (Qtw-pot) from baseline from pre to post cycling exercise measured with supra maximal femoral nerve electro stimulation. The central fatigue was estimated from voluntary activation (VA) using the superimposed twitch technique. The central motor drive (CMD) was estimated from quadriceps EMG (mean RMS normM). On different days, both groups performed two maximal cycle tests in the 1 min TT and the 10 min TT where each TT was repeated two times as test 1 and test 2 with neuromuscular assessment between tests. The reduction in Qtw-pot from baseline was not significant different from test 1 to test 2 ( $P < 0.07$ ) and indicate the fatigue threshold. The training status influence on the fatigue threshold and performance was the same for anaerobic 1 min TT and aerobic 10 min TT. The endurance-trained group had a lower reduction in Qtw-pot from baseline that means a lower fatigue level on the fatigue threshold ( $P < 0.01$ ), a higher CMD ( $P < 0.05$ ) and higher power output ( $P < 0.01$ ) than the recreational group. The 1 min TT had a higher reduction in Qtw-pot and a higher level of fatigue on the fatigue threshold than the 10 min TT. The central fatigue increase from test 1 to test 2 and had higher influence on the aerobic 10 min TT than the anaerobic 1 min TT. The results show that quadriceps fatigue related to biochemical changes in the muscle and central fatigue related to decrease in VA was responsible for the fatigue threshold and decrease in performance. These findings show that training status have an influence on the fatigue threshold and performance where higher training status leads to higher fatigue threshold and performance.

# Acknowledgement

I would like to thank NTNU, Trondheim and the University of Nice, Sophia Antipolis, Faculty of Sport Science, France for the cooperation between the universities. I am grateful for the opportunity to write my master thesis in cooperation with the University of Nice, Sophia Antipolis, and Faculty of sport science.

I would like to thank my supervisor Karin Roeleveld in NTNU, Trondheim for expertise, supervision and assistance during the analysis and writing process of the master thesis.

I would like to thank my supervisor in the University of Nice Gregory Blain for introducing me to this exiting field exercise fatigue, for high expertise and supervision on the field, preparations and laboratory assistance.

I would thank my collaborator PhD student Guillaume Ducrocq in the University of Nice, Sport Faculty for recruitment and communication with the subjects and all the hours with cooperation with preparations, laboratory testing of the subjects, data collection and supervision with analysis. I will also thank my classmates and specially Astrid Kahrs Dykesteen and Yngvild Gagnat for support and meaningful discussions during our semester in Nice, France.

# Contents

- Abbreviations..... 5
- 1 Introduction ..... 6**
- 2 Methods ..... 9**
  - 2.1 Subjects..... 9**
  - 2.2 Measurement methods and protocol..... 9**
    - 2.2.1 Power output and performance ..... 9
    - 2.2.2 Electro stimulation ..... 10
    - 2.2.3 Electromyography ..... 11
    - 2.2.4 Exercise responses ..... 12
    - 2.2.5 Protocol ..... 12
  - 2.3 Statistical analysis..... 14**
- 3 Results ..... 15**
  - 3.1 Peripheral fatigue and voluntary activation ..... 15**
  - 3.2 Electromyography ..... 16**
  - 3.3 Power output ..... 17**
  - 3.4 Exercise responses ..... 17**
- 5 Discussion ..... 23**
  - 5.1 Fatigue threshold ..... 23**
  - 5.2 The training status influence on the fatigue threshold..... 24**
  - 5.3 Central motor drive and power output ..... 25**
  - 5.4 Conclusions..... 26**
- 6 References ..... 28**

## Abbreviations

Qtw	Unpotentiated quadriceps twitch force
Qtw-pot	Potentiated quadriceps twitch force
VA	Voluntary activation
EMG	Electromyography
CMD	Central motor drive
MVC	Maximal voluntary contraction
TT	Time trail
VO <sub>2</sub> max	Maximal oxygen uptake test
W <sub>peak</sub>	Peak power output test
RMS	Root mean square
RMSnormM	RMS of the EMGs normalized by the maximal M-wave amplitudes.
VO <sub>2</sub>	Oxygen consumption
VCO <sub>2</sub>	Carbon dioxide production
Ve	Minute ventilation
RPE	Rate perceived exertion
SD	Standard derivation

# 1 Introduction

Muscle fatigue is a process that starts as soon as the exercise begins and develops progressively. Muscle fatigue is defined as any exercise induced reduction in the ability of a muscle or muscle group to generate force or power (Gandevia, 2001). The development of muscle fatigue depends on the exercise intensity and duration, and the greater the force and the intensity produced by a muscle or motor unit during a task the more and faster the muscle will be fatigued (Enoka & Stuart, 1992). The muscle fatigue is task and condition specific, meaning that the details of the task and condition depending on exercise method, muscle groups, fiber type composition, intensity and duration determine the level and mechanism of fatigue (Enoka & Stuart, 1992).

Muscle fatigue can be divided into peripheral fatigue and central fatigue. The peripheral fatigue is defined as fatigue produced by changes at or distal to the neuromuscular junction (Gandevia, 2001) with changes like modification of excitation contraction coupling, increase of metabolic substrates and intracellular milieu (Enoka & Stuart, 1992). This lead to a decrease in the contractile strength of the muscle fibers and changes in the mechanisms underlying the transmission of muscle action potentials (Gandevia, 2001). The peripheral fatigue can be demonstrated as a reduction in the potentiated quadriceps twitch force ( $Q_{tw-pot}$ ) from baseline values measured with electrical nerve stimulation (Enoka & Stuart, 1992).

Muscle fatigue can also be caused by failure in the central nervous system. Central fatigue is defined as a progressive exercise-induced reduction in voluntary activation or neural drive to the muscle and it can occur at both the spinal and supraspinal level (Allen et al. 1998; Gandevia, 1996.). The central fatigue is often demonstrated as a reduction in central motor drive (CMD) and reduction in voluntary activation (VA) of the muscle. The central motor drive (CMD) is neural drive from the brain consisting of commands about recruitment of motor units to muscle contraction, and estimated by electromyography signals of the muscle (Enoka & Stuart, 1992). The voluntary activation (VA) is defined as the level of voluntary drive during the effort (Enoka & Stuart, 1992; Gandevia, 2001) and can be demonstrated by the superimposed twitch technique (Merton, 1954): Supra-maximal superimposed electrical stimulation on the maximal voluntary contraction (MVC) compared with the force subjects can occur by voluntary activation (Merton, 1954). The increase of force produced by supra-maximal superimposed electrical stimulation on the MVC compared to the MVC indicates failure in VA and central fatigue (Gandevia, 1996).

During prolonged exercise performance, fatigue reaches the fatigue threshold when the subject is no longer able to increase or maintain constant force or intensity and the performance has to decrease to continue the exercise (Amann & Dempsey, 2008). It is known that there exists a fatigue threshold, which is the highest level of peripheral fatigue (Amann & Dempsey, 2008; Hureau et al, 2014) and the upper sensory limit that a muscle can tolerate (Gandevia, 1996). Studies show that the level of peripheral fatigue was identical at the end of exercise to exhaustion independent of degree of pre-exercise fatigue before the test (Amann & Dempsey, 2008; Hureau et al, 2014). Time trials performed with different levels of pre-exercise fatigue and from a fresh condition ended at an identical level of peripheral fatigue at the end of the time trial and indicates the fatigue threshold (Amann & Dempsey, 2008; Hureau et al, 2014). The theory about fatigue threshold has been documented in different exercises and methods like single leg knee exercise to exhaustion and cycling exercise (Amann & Dempsey, 2008; Amann et al. 2009, 2013; Froyd et al. 2013; Hureau et al. 2014) and one study has compared different conditions on the fatigue threshold (Amann et al. 2007). This study compared the influence of different oxygen supply on the fatigue threshold and found a lower fatigue level on the fatigue threshold in hypoxia compared to normoxia and speculate that the fatigue threshold is task and condition specific (Amann et al. 2007).

The identical level of peripheral fatigue at the end of exercise shows that power output and performance were adjusted during the exercise to limit the development of peripheral fatigue beyond a critical threshold. Group III and IV muscle afferents play an important role in the regulation of muscle fatigue during exercise by regulating the CMD down to the peripheral muscles (Amann & Dempsey, 2008; Amann et al. 2011, 2013). The regulation loop of peripheral fatigue starts and ends in the muscle. Onset of exercise metabolites in the muscle affect stimulation of group III and IV muscle afferents up to the motor cortex. Group III and IV muscle afferents send information about the degree of metabolites and fatigue in the muscle. High peripheral fatigue in the muscle leads to a decrease in the CMD down to the peripheral muscle and lower CMD leads to a decrease in power output and performance (Amann & Dempsey, 2008; Amann et al. 2011, 2013; Hureau et al, 2014). Group III and IV muscle afferents have an inhibitory influence on CMD and performance were shown by blockade of lower limb thin-fibre muscle afferents with fentanyl injection (Amann et al. 2009, 2011). Blockade of group III and IV muscle afferents resulted in overload of CMD, a higher power output and performance and a faster development of peripheral fatigue than activated with intact group III and IV muscle afferents (Amann et al, 2009). Moreover, blockade of group III

and IV muscle afferents impaired cardiorespiratory responses and O<sub>2</sub> delivery that resulted in a faster development of muscle metabolites and peripheral fatigue (Amann et al. 2010, 2011). Inhibition of those afferents had a more negative influence on exercise performance and fatigue than intact function (Amann et al. 2009, 2010, 2011).

A study has shown a training effect on the sympathetic nervous system after a training regime (Sinoway et al, 1996). Forearm exercise performance compared pre and post a four weeks training regime show a reduction in sympathetic nervous activity. It was speculated that this reduction in sympathetic nerve activity from training was caused by a decrease in sensitivity of group III and IV muscle afferents (Sinoway et al, 1996).

Exercise training might be able to modulate the regulation loop of fatigue by decreasing the sensitivity of group III and IV afferents to metabolite accumulation within the muscle (Sinoway, 1996) and limit the inhibition of CMD and performance during exercise. Speculate that the fatigue threshold is task and condition specific based on the previous findings where muscle fatigue is task and condition specific (Enoka & Stuart, 1992) and the result that show lower fatigue level on the fatigue threshold in hypoxia compare to normoxia (Amann et al. 2007). Based on these theories this study will compare two groups with different training status, a recreational group and an endurance-trained group in aerobic and anaerobic cycling exercise to exhaustion to **determine the influence of training status on the fatigue threshold and performance during high intensity exercise.**



## 2 Methods

### 2.1 Subjects

Competitive endurance trained cyclists with high performance were invited to the endurance-trained group and low to medium trained students were invited to the recreational group in the present study. The endurance-trained group consisting of six professional cyclists from a cycling team and the recreational group consisting of seven volunteer students from the sport faculty at a university. All subjects were healthy no smokers, received a presentation with information about the study before start and could cancel at any time during the study.

Subject information Mean $\pm$ SD	Endurance trained group	Recreationally group
Age	23.2 $\pm$ 3.9	21.6 $\pm$ 0.7
Body mass	68.1 $\pm$ 1.9	72.6 $\pm$ 5.2
Height	179.8 $\pm$ 2.8	180.9 $\pm$ 2.4
Body fat	10.3 $\pm$ 0.7	13.6 $\pm$ 1.8
VO <sub>2</sub> max	75.3 $\pm$ 2.5	52.9 $\pm$ 3.4

### 2.2 Measurement methods and protocol

All participants visited the lab at least seven times of which two visits with maximal cycle tests performed as a 1 minute and 10 minute time trail (TT), respectively. Each TT was repeated two times as test 1 and test 2 with assessment of neuromuscular function between tests. Prior to these TT-visits, they had at least four visits with familiarizations, and one visit with a peak power output test ( $W_{peak}$ ) followed by a maximal oxygen uptake test (VO<sub>2</sub>max). To evaluate peripheral and central fatigue, several tests were performed prior to and after the TTs. The measurement methods and detailed protocol are described below.

#### 2.2.1 Power output and performance

A magnetic braked ergometer cycle (Watt bike pro, Nottingham, United Kingdom) interfaced with a laboratory computer was used to complete 1 min TTs and 10 min TTs cycling and measure power output (Watt) and performance with self-pacing strategy. The magnetic braked ergometer cycle was regulated and adapted to each participant. Position of seat height,

handlebar height and length from seat to handlebar were standardized to each participants with same positions for all visits. The TTs were performed with self-pacing strategy with self-regulated gear, time information and encouragement. Subjects remained seated during the exercise.

### 2.2.2 Electro stimulation

MVC and electro stimulation were done in a custom made chair with the right thigh resting in a standardized holder with the knee joint angle at 90 degrees and the trunk- thigh angel at 135 degrees. The arms were folded across the chest during the tests. An electrical stimulator (DS7A, Digitimer, Hertfordshire, United-Kingdom) was used to stimulate the femoral nerve at femoral triangle. A self-adhesive Ag/AgCl surface electrode was placed at the femoral triangle (Mini-KR, 30x30, Contrôle-Graphique, Brie-Comte-Robert, France) and a reference elastomer electrode (Compex SA, Ecublens, Switzerland, 80mmX5mm) was filled with conductive gel and placed at the ischial tuberosity.

To measure the unpotentiated quadriceps twitch force (Qtw), a calibrated load cell (Model SM-2000N, Interface, Scottsdale, AZ, USA) was fastened to the right ankle with a strap placed superior to the malleoli. The placement of force sensor was adapted to each participant with the sensor at horizontal direction and in line with the right leg. To be sure that the electro stimulation was supramaximal, single Qtw was measured every 30s at 50, 60, 70, 80, 85, 90, 95 and 100% of maximal stimulator power output. The electro stimulation was supramaximal when a plateau in Qtw and M-wave with increased stimulus intensity was observed and indicate maximal recruitment of motor units. Supramaximal stimulation intensity was used during neuromuscular function assessments.

Two visits with maximal cycle tests were performed as a 1 min and 10 min TT, where each TT was repeated two times as test 1 and test 2 with assessment of neuromuscular function between tests. Neuromuscular function including potentiated single quadriceps twitch force (Qtw-pot) and voluntary activation (VA) were assessed in blocks with six blocks before the TT, four blocks between the two TT and six blocks after the second TT. One block consisted of 5 seconds MVC with superimposed doublet twitch 100 HZ on the MVC followed by three electro stimulations with potentiated doublet twitch 100 HZ, potentiated doublet twitch 10 HZ and potentiated single quadriceps twitch force (Qtw-pot). The three electrostimulations were measured 3, 6 and 9 seconds after the MVC standardize from the power lab system

(PowerLab 16/35- ML138, Labchart 7, ADInstruments, Bella Vista, Australia). The peripheral fatigue was calculated from the potentiated single quadriceps twitch force (Qtw-pot). Qtw-pot is a more reproducible and a more sensitive measure of fatigue compare to Qtw without MVC before the stimulations (Kufel et al. 2002). Peripheral fatigue was expressed as reduction in the Qtw-pot from baseline from pre to post cycling exercise. Voluntary activation of quadriceps motor units (VA) was estimated using the superimposed twitch technique (Merton, 1954) with this formula: Voluntary Activation (%) =  $(1 - \text{Superimposed Twitch} / \text{Mean Control Twitch}) \times 100$  (Allen et al., 1995) where mean control twitch was the Qtw-pot (Allen et al. 1995). The assessment of neuromuscular function was done 15 sec post TT to minimize failure estimation of VA caused by central fatigues fast recovery (Gandevia, 1996).

### 2.2.3 Electromyography

The Quadriceps electromyography (EMG) were recorded from right vastus lateralis, vastus medialis, rectus femoris and biceps femoris. The quadriceps EMG from vastus lateralis, vastus medialis, rectus femoris estimate the central motor drive (CMD). The EMGs were measured using two Ag/AgCl surface self-adhesive electrodes on each muscle (Mini-KR, 30mmX30mm, Contrôle-Graphique, Brie-Comte\_robort,France, distance between electrodes 25mm). The EMGs were amplified and filtered with bandwidth frequency, 10 Hz to 1 kHz and recorded using EMG power lab system (PowerLab 16/35- ML138, Labchart 7, ADInstruments, Bella Vista, Australia). The EMGs were sampled every fifth second during the 1 min TT and sampled every 50 second during the 10 min TT. The root mean square of the EMGs normalized by the maximal Mwave amplitude (mean RMS normM) were calculated of the raw values of the EMG signals. The electrodes were placed in a bipolar electrode configuration over the middle of the muscle bundle after Seniam recommendation. The electrode placement for vastus lateralis was 2/3 on the line from the spina iliaca anterior superior to the lateral side of the patella. The placement for the vastus medialis was 80% on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament. The placement for the Rectus femoris was 50% on the line from the anterior spina ilaca superior to the superior part of the patella and the placement for biceps femoris was 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. The reference electrode was placed over the electronically neutral patella. The skin was shaved, rubbed with emery paper and wash with alcohol to occur an impedance

below  $3k\Omega$  and minimize noise. Optimal electrode signal and placement were checked before start for all participants. The electrode placement was adjusted to optimize the signal at some participants. The positions of electrodes were marked to ensure identical location in the next visit.

#### 2.2.4 Exercise responses

Ventilation and pulmonary gas exchange were measured breath by breath at rest and during exercise using an automatic ergospirometer MS-CPX, Viasys, San Diego, CA, USA).

Participants breathed throughout a silicon facemask connected to one pneumotachograph (MS-CPX, Viasys, San Diego, CA, USA) for inspiration and expiration. Arterial O<sub>2</sub> saturation (Sp,O<sub>2</sub>) was estimated using a pulseoximeter. Gas analyses was calibrated using a certified gas preparation (Oxygen 15% and CO<sub>2</sub> 5.8%)

For each TT the variables oxygen consumption (VO<sub>2</sub>), carbon dioxide production (VCO<sub>2</sub>), minute ventilation (V<sub>e</sub>), heart rate and lactate were measured and calculated during the tests. The VO<sub>2</sub>, VCO<sub>2</sub> and V<sub>e</sub> were sampled every fifth second during the 1 min TT and sampled every 50 second during the 10 min TT. The heart rate was measured continuous during the tests from the R-R interval of an electrocardiogram using a heart rate monitor (Polar RS800, Polar Electro, Kempele, Finland). Capillary blood lactate samples (5 $\mu$ L) were collected from a fingertip at rest and 3 min post-exercise (Lactate pro 2, Arkray, Kyoto, Japan). Modified Borg scale- CR10 were used to determine perceived exertion (RPE) every minute during 10 min TT cycling exercise (Borg, 1882).

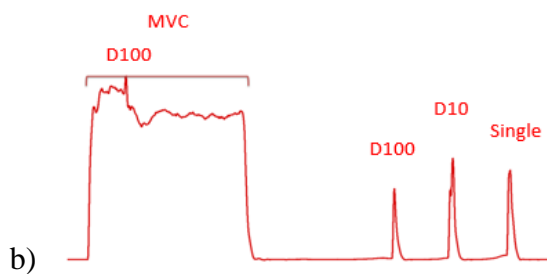
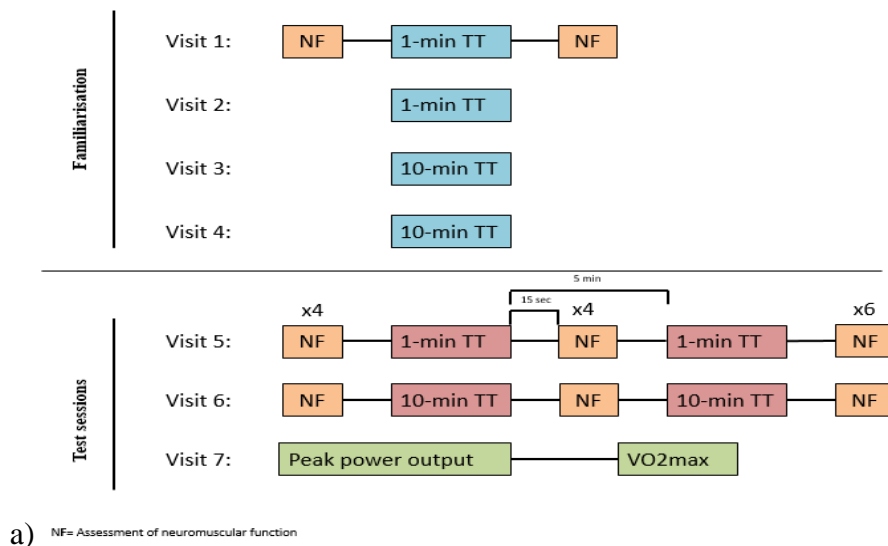
#### 2.2.5 Protocol

The participants visited the lab at least seven times with familiarizations, two visits with a maximal cycle test performed as a 1 min and 10 min TT and one visit with a W<sub>peak</sub> test followed by a VO<sub>2</sub>max test (see fig. 1a). At least four familiarization visits, two on each TTs, were performed on separate days with randomized 1 min TT and 10 min TT. The participants did only one TT on each visit. All subjects were thoroughly familiarized with neuromuscular assessments, maximal voluntary contraction (MVC), electro stimulation and TTs. The criterion to start the two visits with a maximal cycle test was a maximum 3 % difference in power output between identic TTs and stabilized MVCs in the familiarization visits. The first

familiarization included supramaximal electro stimulations, MVCs and two blocks of neuromuscular assessment followed by randomized TT with 6 MVCs after the TT. The second to fourth visits included MVCs without electro stimulation before and after the randomized TT.

On different days, the two visits with maximal cycle test in the 1 min TT and the 10 min TT were performed in random order. In the maximal cycle tests, each TT was repeated two times as test 1 and test 2 with assessment of neuromuscular function between tests. The subjects did not know about test 2 before completing test 1. Neuromuscular function including Qtw-pot and VA were assessed in blocks (see fig. 1b). One block was repeated 6 times each 30 second before test 1 and 4 times at 15 sec, 1 min, 2min and 4 min after test 1 and the subjects started test 2 5 min after test 1 was finished. Neuromuscular assessment after test 2 was at 15 sec, 1 min, 2 min, 4 min, 6min and 15min. Exercise responses like pulmonary, cardiac and respiratory variables were measured during the TT.

On a separate day, the subjects performed a peak power output test ( $W_{peak}$ ) (5X5 sec with different workload) and a maximal oxygen consumption test ( $VO_{2max}$ ), starting at 135 watt and increased with 25 watt every second minute until exhaustion ( $135w + 25w \text{ pr. } 2\text{min}$ ). These tests were performed on a magnetic braked cycle ergometer (Wattbike pro, Nottingham, United Kingdom) to determined  $VO_{2max}$  and  $W_{peak}$ . Pedal frequency was set to be 80 revolutions per minute during the test. When the pedal frequency decline below 80 revolutions per minute and when the subject was not able to increase to 80 revolutions per minute with encouragement the test was finish. The subjects remained seated during exercise and had no feedback from power, pedal frequency and distance. Each session was separated by 48h-7 days and exercise was performed at the same time of the day. No sport last 24h before test and no caffeine and alcohol last 12h before test. Ambient temperature ( $21 \pm 2 \text{ C}^\circ$ ) and humidity ( $43 \pm 2\%$ ) were not different between the visits. Question about training level, type of sport and frequency of training in familiarization visits.

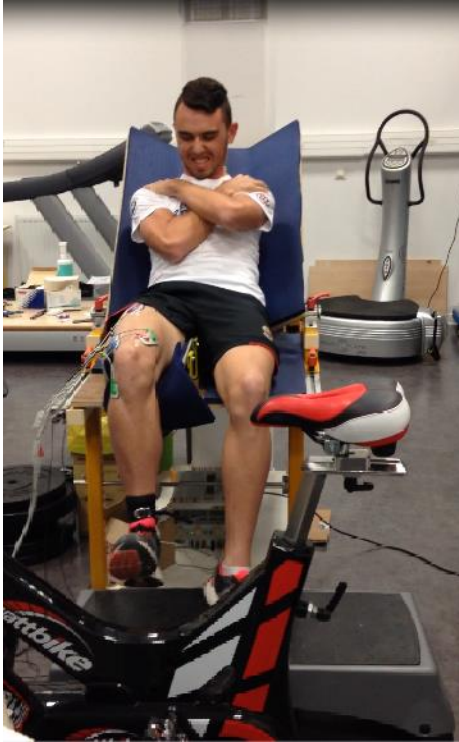


**Figure 1. Schematic illustration of the experimental design.**

Subjects visit the lab at least 7 times illustrated in figure 1a. They performed at least four visits with familiarizations, followed by the two visits with maximal cycle test performed as a 1 minute and 10 minute time trail (TT) and one visit with a peak power output test ( $W_{peak}$ ) followed by a maximal oxygen uptake test ( $VO_{2max}$ ). The assessment of neuromuscular function (NF) including Qtw-pot, VA were assessed in blocks illustrated in figure 1b. Superimposed doublet twitch 100Hz on the MVC followed by potentiated doublet twitch 100Hz, potentiated doublet twitch 10Hz and potentiated single twitch (Qtw-pot). NF only in the first familiarization visit and in the visits with the two maximal cycle tests.

## 2.3 Statistical analysis

The exercise responses, EMG and power output data presented in the results are expressed as mean  $\pm$  SD. The Qtw-pot and lactate data are expressed as mean  $\pm$  95 % confidence interval. All variables were tested for normal distribution with descriptive statistics, explore analysis. Linear mixed models analysis were used to test the main effect and interaction between groups, tests and TTs in Qtw-pot, VA, EMG meanRMS norm, power output and exercise responses. Statistical analyses were conducted using SPSS 21 (IBM SPSS Statistics 21, Armonk, NY, USA. Statistical significance was set at  $P < 0.05$ ).



**Figure 2. Picture of the assessment of neuromuscular function (NF) with the bike used to complete the time trail to exhaustion in the front.**

## **3 Results**

### **3.1 Peripheral fatigue and voluntary activation**

The level of peripheral fatigue measured with Quadriceps potentiated twitch (Qtw-pot) 15 sec post 1 min TT and 10 min TT for the endurance-trained and the recreational group are illustrated in figure 3. The Qtw-pot show how fatigued the muscle was on the fatigue threshold. There was a significant difference in Qtw-pot between groups where the endurance-trained group had a lower percent reduction in Qtw-pot from baseline compare to the recreational group in 1 min TT and 10 min TT (Group effect  $P < 0.01$ ). There was a significant difference in Qtw-pot between the TTs where the 1 min TT develop a higher reduction in Qtw-pot from baseline than 10 min TT (Time trail effect  $P < 0.01$ ). The reduction in Qtw-pot 15 sec post TTs were not significant different between test 1 and test 2 (Test effect  $P > 0.07$ ), though show a trend to different fatigue level in the 10 min TT. The groups was not significant different between the TTs (Group\*TT effect  $P > 0.50$ ) and the groups and tests was

not significant different between the TTs (Group\*test\*TT  $P>0.11$ ). The voluntary activation (VA) 15 sec post TT for the endurance-trained group and the recreational group are shown in table 1. Voluntary activation (VA) changed significantly between the TTs where the 1 min TT had a lower reduction in VA from baseline than the 10 min TT (time trail effect  $p<0.01$ ). The VA changed significantly between tests where the reduction in the VA decrease in level from test 1 to test 2 in the 1 min TT and the 10 min TT (test effect  $P<0.01$ ). There was no difference in VA-change between the groups (group effect  $>0.47$ ). The groups were not significant different between the TTs (Group\*TT effect  $P>0.44$ ) and the groups and tests were not significant different between the TTs (Group\*test\*TT  $P>0.09$ ).

### **3.2 Electromyography**

Figure 4 illustrate the EMG activity for Vastus lateral, Vastus medialis and Rectus femoris for the endurance-trained and the recreational group in 1 min TT and 10 min TT. There was a difference in the EMG activity for Vastus lateralis between the groups where the endurance-trained group had a higher level of EMG activity compared to the recreational group throughout the TTs (Group effect  $P<0.01$ ). There was a difference in EMG activity between the TTs with a higher level and increase in the 1 min TT and a plateau in a lower level with a sprint at the end in the 10 min TT (Time trail effect  $P<0.01$ ). There was found only a trend to significant difference between tests with decrease in level of EMG activity from test 1 to test 2 from 45sec/450sec to the end of TTs for both groups in 10 min TT and only the recreational group in 1 min TT (Test effect  $P<0.06$ ). The groups were not significant different between the TTs (Group\*TT effect  $P>0.19$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P>0.32$ ).

The EMG activity for Vastus medialis was different between the groups from start to 25sec/250sec with a higher level of EMG activity in the endurance group than the recreational group (Group effect  $P<0.05$ ). There was a difference in the EMG activity for vastus medialis between the TTs with a higher level and increase in the 1 min TT and a plateau in a lower level with a sprint at the end in the 10 min TT (time trail effect  $P<0.01$ ). There was a significant difference between tests where test 1 had a higher level of EMG activity from 20sec/200sec to the end of TTs compare to test 2 (Test effect  $P<0.05$ ). The groups were not significant different between the TTs (Group\*TT effect  $P>0.46$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P>0.28$ ).



The EMG activity for rectus femoris was different between the TTs, with a higher level of EMG activity in the 1 min TT compare to a lower level in the 10 min TT (Time trail effect  $P < 0.01$ ). There was found that the groups were significant different between the TTs from start to 55sec/550sec where the groups in the 1 min TT had a higher level of EMG activity and a greater difference between groups compare to the groups in the 10 min TT (Group\*TT effect  $P < 0.05$ ). There was no difference in the EMG activity for rectus femoris between the groups (Group effect  $P > 0.28$ ). There was no difference in the EMG activity for rectus femoris between the tests (Test effect  $P > 0.15$ ) and the groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.53$ ).

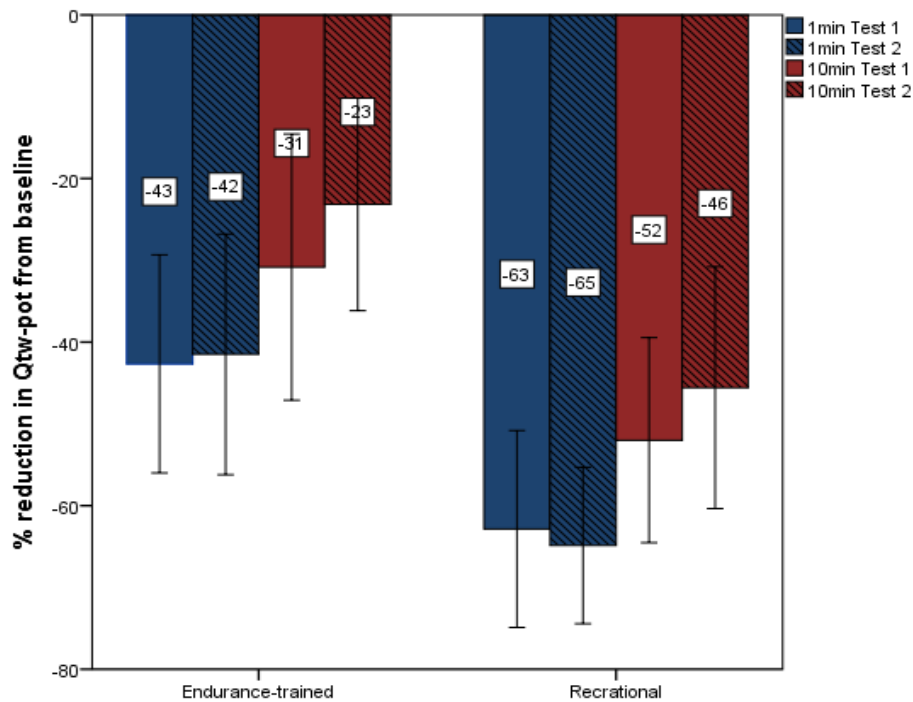
### **3.3 Power output**

Figure 5 illustrates mean power output during the 1 min and the 10 min TT for the endurance-trained group and the recreational group. There was a significant difference in power output between groups where the endurance-trained group had a higher level of power output from 10sec/100sec to the end than the recreational group (Group effect  $P < 0.01$ ). There was a significant difference in power output between TTs from 5 sec/50sec to 55sec/550sec where the 1 min TT reduced gradually from the start to the end and the 10 min TT had a reduction from start, a plateau and increase at the end (Time trail effect  $P < 0.01$ ). There was a difference in power output between tests where test 1 was in a higher level of power output than test 2 (Test effect  $P < 0.05$ ). There was found that the groups were significant different between the TTs from 5 sec/50sec to 55sec/550sec where the 1 min start in a high power output and decrease during the TT and the 10 min TT had a reduction from start, a plateau and increase at the end (Group\*TT effect  $P < 0.05$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.09$ ).

### **3.4 Exercise responses**

Figure 6 illustrate physiological responses during 1 min TT and 10 min TT for the endurance-trained group and the recreational group. The endurance-trained group had a higher  $VO_2$  from start to 55sec/ 550 sec compare to the recreational group (Group effect  $P < 0.01$ ). The other physiological measures (VE, HR, Lactate and RPE) were not different between the groups (Group effect  $P > 0.11$ ). There was a difference between TTs for variables  $VO_2$ , Ve, heart rate

and lactate (Time trail effect  $P < 0.03$ ). Increase from start and showed a short plateau at the end of the 1 min TT, while those variables had a fast increase from start and stabilized early to a plateau during the 10 min TT. The 1 min TT ended with a higher level of  $V_e$  and lactate accumulation than the 10 min TT, and the 10 min TT had a higher heart rate than the 1 min TT. There was a difference between the tests for  $VO_2$ ,  $V_e$ , heart rate with faster increase at the beginning of test 2 compare to test 1 (Test effect  $P < 0.03$ ). The subjects report higher values of RPE from 4 min to 9 min in test 2 compare to test 1 (Test effect  $P < 0.04$ ), but ended at similar values of RPE (9,6 RPE for the endurance-trained group and 9,8 RPE for the recreational group). There was found that the groups were not significant different between the TTs (Group\*TT effect  $P > 0.15$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.21$ ).



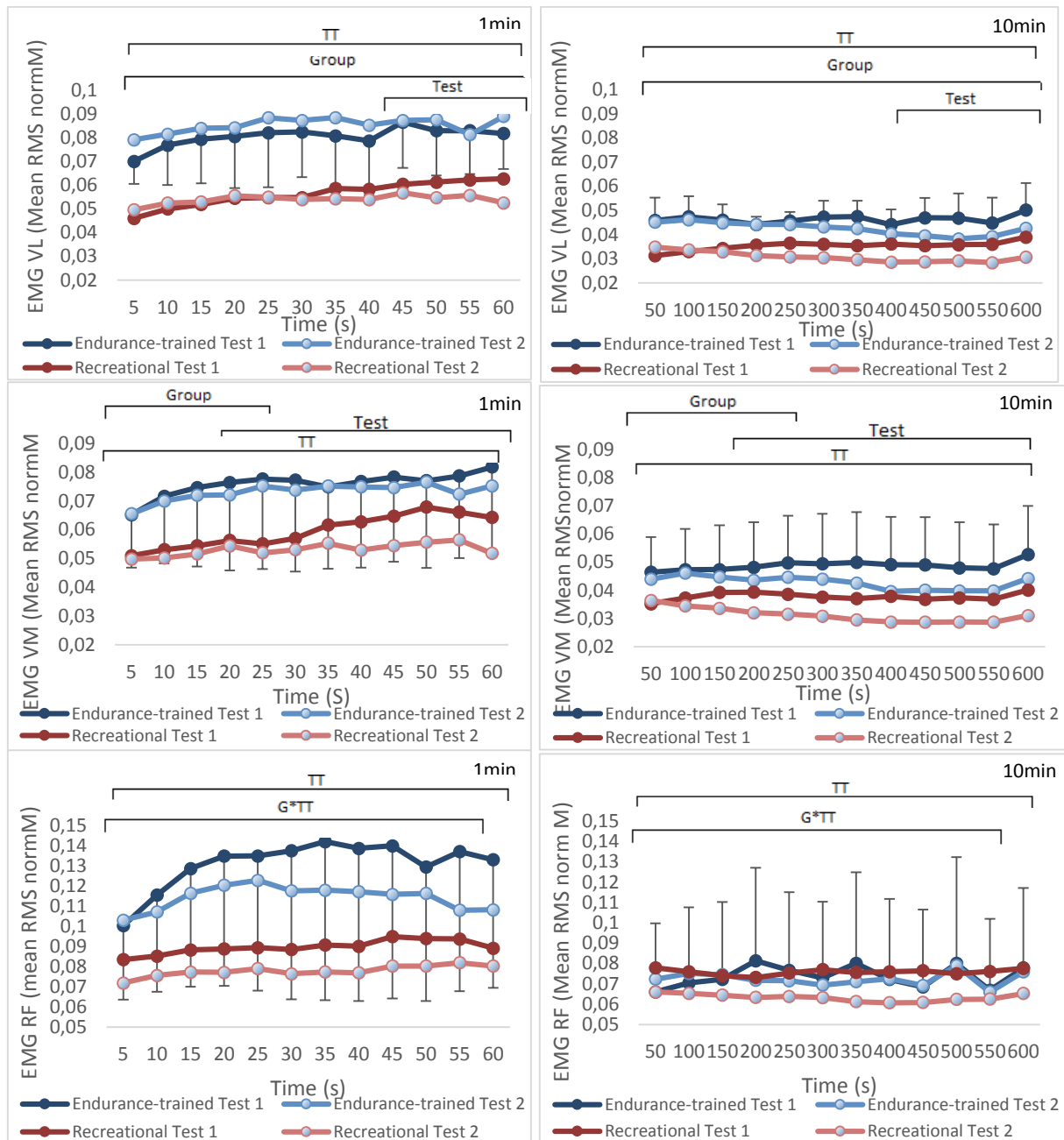
**Figure 3. Peripheral fatigue presented as a percent group mean reduction in potentiated single quadriceps twitch force (Qtw-pot) from baseline to 15 second post 1 min and 10 min TT for the endurance-trained and the recreational group.**

The Qtw-pot show how fatigued the muscle was on the fatigue threshold. The 1 min TT are presented in blue bars and the 10 min TT are expressed in red bars. Peripheral fatigue are expressed as the percent reduction in Qtw-pot from baseline. The values are expressed as means  $\pm$  95 % confidence interval. Significant difference between groups (Group effect  $P < 0.01$ ). Significant difference between TTs (Time trail effect  $P < 0.01$ ). A trend to significant difference between test 1 and test 2 (test effect  $P > 0.07$ ). The groups was not significant different between the TTs (Group\*TT effect  $P > 0.50$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.11$ ). The Endurance-trained group,  $N = 6$ , the recreational group  $N = 7$  and total  $N = 13$ .

**Table 1. Central fatigue presented as a percent group mean reduction in VA from baseline 15 second post 1 min and 10 min TT for the endurance-trained group and the recreational group.**

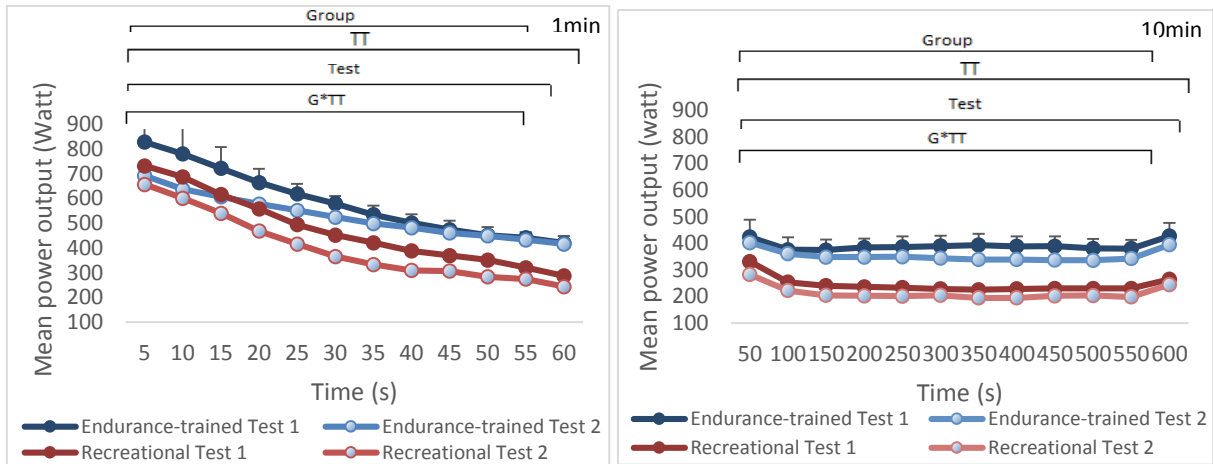
	Endurance-trained group				Recreational group			
	1min Test 1	1 min Test 2	10min Test 1	10min Test 2	1min Test 1	1min Test 2	10min Test 1	10min Test 2
VA $\Delta\%$ from baseline	-4 $\pm$ 4	-7 $\pm$ 8	-6 $\pm$ 5	-11 $\pm$ 8	-4 $\pm$ 5	-7 $\pm$ 13	-8 $\pm$ 11	-7 $\pm$ 11

Voluntary activation (VA) are expressed as a percent change from baseline to 15 sec post TT. The values are expressed as means  $\pm$  SD. Voluntary activation is based on superimposed twitch technique. Significant difference between TTs (Time trail effect  $P < 0.01$ ). Significant difference between tests (Test effect  $P < 0.01$ ). No significant difference between groups (group effect  $P < 0.47$ ). The groups were not significant different between the TTs (Group\*TT effect  $P > 0.44$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.09$ ). The Endurance-trained group,  $N = 6$ , the recreational group,  $N = 7$  and total  $N = 13$ .



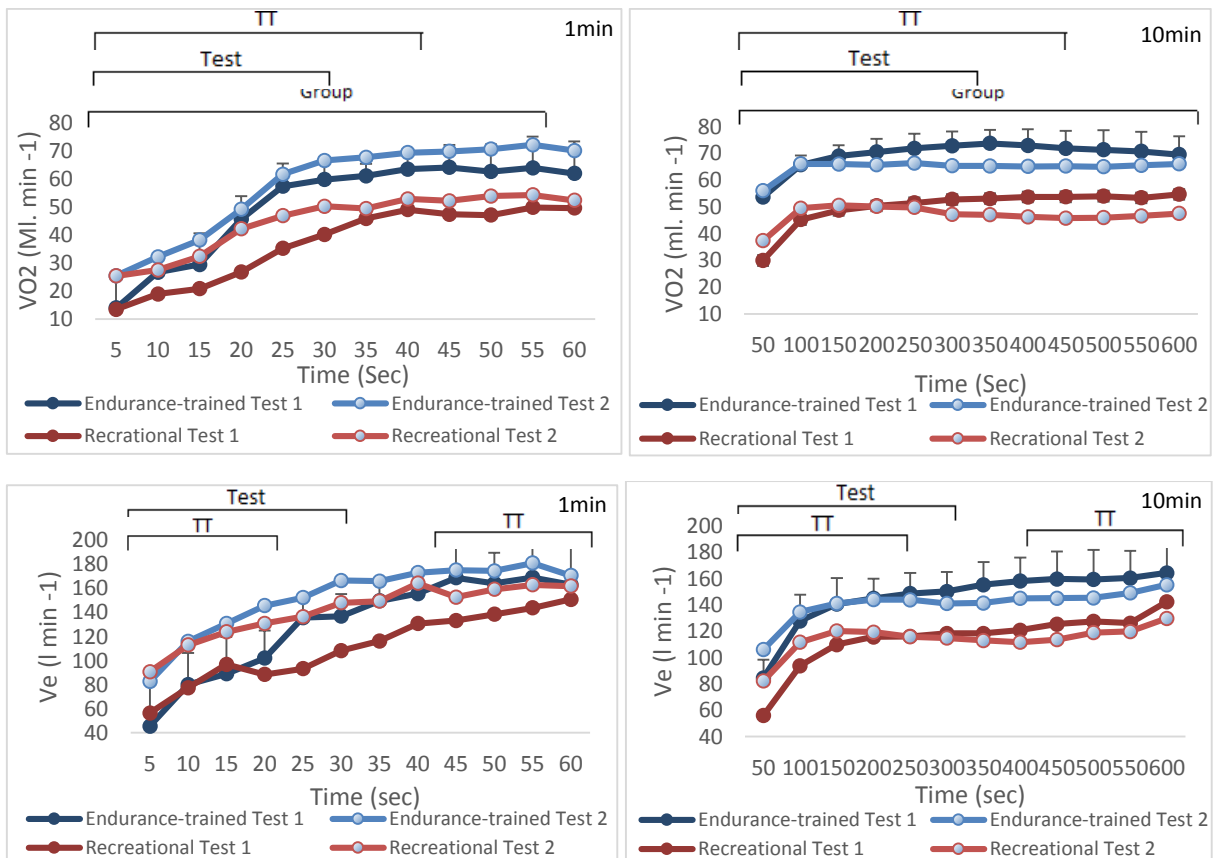
**Figure 4. Central motor drive estimated by EMG (mean RMS normM) of Vastus Lateralis (VL), Vastus medialis (VM) Rectus femoris (RF) during 1 min TT and 10 min TT.**

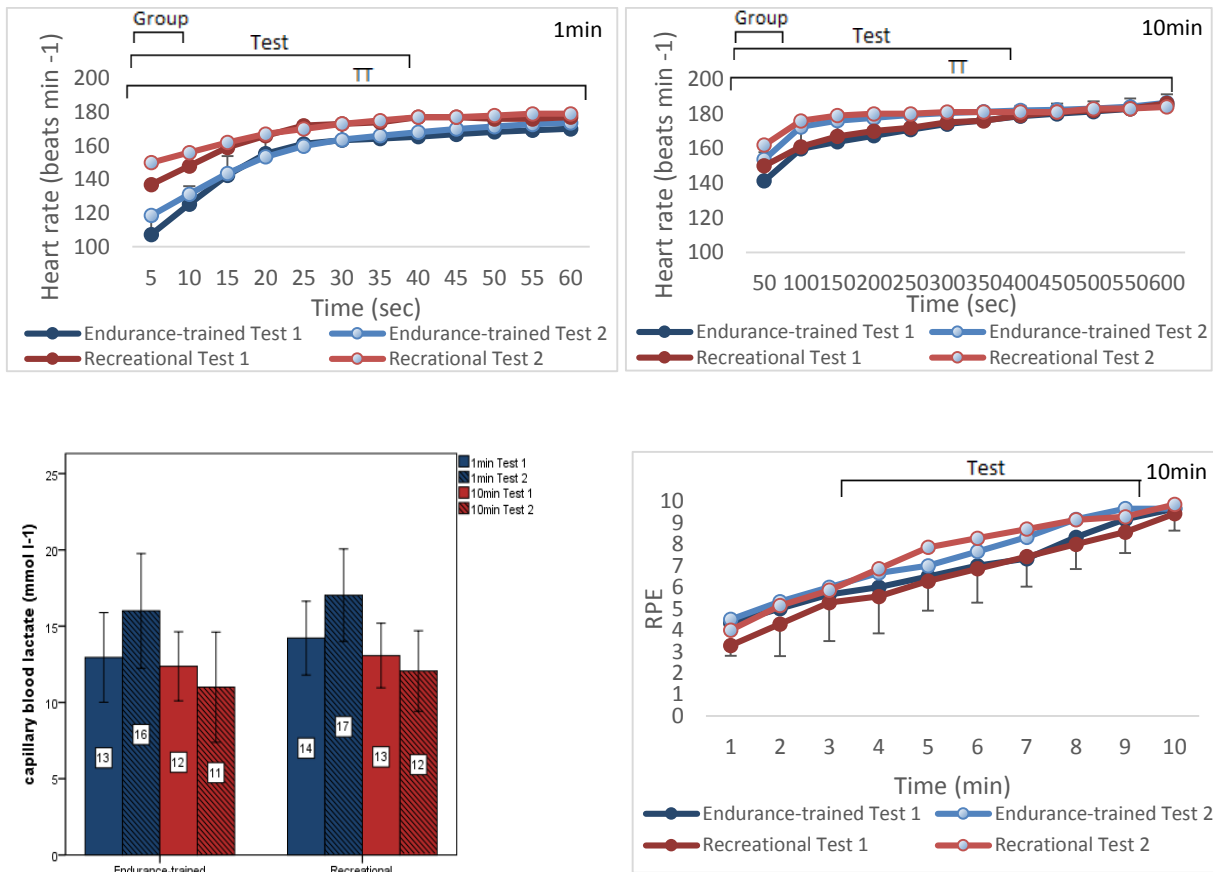
EMG (mean RMS norm) estimate central motor drive (CMD) for Vastus Lateralis (VL), Vastus Medialis (VM), Rectus femoris (RF). The 1 min TT are presented to the left and 10 min TT to the right. The endurance-trained group are expressed in blue bars and the recreational group in red bars. Dark and light color shows test 1 and test 2. The root mean square (RMS) of the EMGs were normalized by the maximal M-wave amplitudes. The values are expressed as means  $\pm$  SD. Significant difference between groups (Group effect  $P < 0.05$ ). Significant difference between TTs (Time trail effect  $P < 0.05$ ) Significant difference between tests (Test effect  $P < 0.05$ ). The groups were significant different between the TTs for RF (Group\*TT effect  $P < 0.05$ ) and not significant for VL and VM (Group\*test effect  $P > 0.19$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.28$ ). The Endurance-trained group,  $N = 6$ , the recreational group,  $N = 7$  and total  $N = 13$ .



**Figure 5. Group mean variations in power output (W) during 1 min TT and 10 min TT.**

The 1 min TT are presented to the left and 10 min TT to the right. The endurance-trained group are expressed in blue bars and the recreational group in red bars. Dark and light color shows test 1 and test 2. Significant difference between groups (Group effect  $P < 0.01$ ). Significant difference between TTs (Time trail effect  $P < 0.01$ ). Significant difference between tests (Test effect  $P < 0.05$ ). The groups were significant different between the TTs (Group\*TT effect  $P < 0.05$ ). The groups and tests were not significant different between the TTs (Group\*test\*TT  $P > 0.09$ ).  $N = 13$ . The Endurance-trained group,  $N = 6$ , the recreational group,  $N = 7$  and total  $N = 13$ .





**Figure 6. Mean physiological responses of maximal oxygen consumption (VO<sub>2</sub>), minute ventilation (V<sub>e</sub>), heart rate, rated perceived exertion (RPE) and lactate during two 10 min TT and two 1 min TT to exhaustion for the endurance-trained group and the recreational group.**

Mean physiological responses of Vo<sub>2</sub>, V<sub>e</sub>, heart rate, RPE and lactate. The endurance-trained group are presented in blue lines and the recreational group in red lines. Dark and light colors show test 1 and test 2. The values are expressed as means ± SD and lactate with 95 % confidence interval. Significant difference between groups for VO<sub>2</sub> (Group effect P<0.01) Significant difference between TTs for variables VO<sub>2</sub>, V<sub>e</sub>, heart rate and lactate (Time trail effect P<0.03). Significant difference between tests for Vo<sub>2</sub>, V<sub>e</sub>, heart rate and RPE (Test effect P<0.04). No significant difference between group for V<sub>e</sub>, heart rate and lactate (Group effect P>0.09). The groups were not significant different between the TTs (Group\*TT effect P>0.15). The groups and tests were not significant different between the TTs (Group\*test\*TT P>0.21). The Endurance-trained group, N= 6, the recreational group, N= 7 and total N=13.

## 5 Discussion

A research from Sinoway, 1996 found a reduction in muscle sympathetic nerve activity pre to post a training regime. Sinoway speculated that the training effect in muscle sympathetic nerve activity was caused by that training decrease the sensitivity of group III and IV afferents to the fatigue level within the muscle (Sinoway, 1996). The endurance-trained group and the recreational group were compared to determine trainings status influences on the fatigue threshold and performance during high intensity exercise. The main findings show that training status have an influence on the fatigue threshold and performance where the endurance-trained group had a lower reduction in Qtw-pot from baseline, higher CMD and power output compare to the recreational group. The trainings status influence on fatigue threshold were examined in anaerobic 1 min and aerobic 10 min TT where the 1 min TT show a higher reduction in Qtw-pot from baseline, a higher CMD and power output compare to the 10 min TT.

### 5.1 Fatigue threshold

To estimate the fatigue threshold, which is the highest level of peripheral fatigue that associated muscle sensory input can tolerate (Amann & Dempsey, 2008; Gandevia, 1996; Hureau et al. 2014) was the variable Qtw-pot compared in test 1 and test 2. The results in figure 3 show no significant difference in Qtw-pot between the tests overall, with an identical level of peripheral fatigue in the 1 min TT, though a small difference and unclear fatigue threshold in the 10 min TT. Identical fatigue level between tests in the 1 min TT supporting the theory about the fatigue threshold documented in both anaerobic cycling exercise with short sprints and aerobic 5 km cycling TT (Amann & Dempsey, 2008; Amann et al. 2009; Hureau et al. 2014). It should be possible based on this theory to determine the fatigue threshold in both the 1 min and 10 min TTs. That the results in the 10 min TT did not show a clear fatigue threshold could be affected by pacing strategy and motivation. Speculating that there was harder to find the right intensity and calculate pacing for the 10 min TT compare to the 1 min TT with short duration. Some of the subjects started too fast and looked like a short sprint before high accumulation of metabolites leads to decrease in intensity. Two identical tests were done on each TT to determine the fatigue threshold and the subjects did not know about test 2 before completed test 1. That exclude that the subjects save energy to test 2 and

ensured that they completed test 1 to exhaustion. The subjects were shocked when they had to complete one more TT to exhaustion who could lead to lack of motivation and performance. Maybe they were not motivated and hard enough with them self to complete a maximal TT to exhaustion in the 10 min TT who affect the results with unclear fatigue threshold in the 10 min TT. The exercise responses during the tests in figure 6 shows that both groups had lactate level above 4mmol, high VO<sub>2</sub> level and the RPE ended between 9 and 10. These variables indicate a high intensity and effort during the TTs, though cannot be sure that there was a maximal TT to exhaustion.

## **5.2 The training status influence on the fatigue threshold**

Figure 3 shows that the training status influence the fatigue threshold and the influence was the same for both 1 min aerobic and 10 min anaerobic TT. The endurance-trained group had a lower reduction in Q<sub>tw</sub>-pot from baseline than the recreational group. Endurance training over time change the muscle fiber type composition to a higher amount of type I muscle fibers, good endurance performance and low development of fatigue (Enoka & Stuart, 1992). The endurance-trained group consisting of good trained cyclists with probably a high level of slow twitch type I fibers and high muscle endurance and the recreational group was medium trained with probably higher level of fast twitch type II fibers and high power over short time.

The lower reduction in Q<sub>tw</sub>-pot from baseline in the endurance-trained group was probably caused by a higher amount of type 1 muscle fibers. This endurance training effect with higher amount of type 1 muscle fibers affect how fatigued the muscle was on the fatigue threshold. The endurance-trained group lower reduction in Q<sub>tw</sub>-pot mean that they had a lower peripheral fatigue level on the fatigue threshold and could develop more Q<sub>tw</sub>-pot on the fatigue threshold compare to the recreational group. The findings that the endurance-trained group with higher training status occur a lower peripheral fatigue level on the fatigue threshold, probably affect and decrease the sensitivity of III and IV muscle afferents up to the brain. These findings support the idea that training reduce the sensitivity of group III and IV afferents up to the brain (Sinoway, 1996).

Figure 3 show a difference in fatigue level on the fatigue threshold between anaerobic 1 min TT and aerobic 10 min TT. The 1 min TT develop a higher reduction in Q<sub>tw</sub>-pot from baseline that means a higher peripheral fatigue level on the fatigue threshold compare to the 10 min TT. Enoka & Stuart (1992) found that the development of fatigue was task and



condition specific. The 1 min TT was an anaerobic condition and required high maximum power over short time with high accumulation of metabolites in the muscles and the 10 min TT was an aerobic condition and required lower intensity over longer time with lower accumulation of metabolites in the muscle (Enoka & Stuart, 1992). The fatigue threshold has been documented in different exercises and methods (Amann & Dempsey, 2008; Amann et al. 2009, 2013; Froyd et al. 2013; Hureau et al. 2014) and one study has compared the influence of different conditions on the fatigue threshold. This study found a lower level of peripheral fatigue on the fatigue threshold in hypoxia compare to normoxia and speculate that the fatigue threshold is task and condition specific (Amann et al. 2007). Our findings that show different fatigue level on the fatigue threshold between groups and TTs indicates that the fatigue level on the fatigue threshold was task and condition specific dependent on training status, fiber type composition, aerobic or anaerobic condition, intensity and duration.

### **5.3 Central motor drive and power output**

The surface EMG signals in figure 4 were not a direct measure of CMD, though were an estimate of CMD for vastus lateralis, vastus medialis and rectus femoris. The estimate of CMD will be affected of accuracy of the EMG surface measurement and can be affected by noise (Yang & Winter, 1983). The results in figure 4 and 5 show that the endurance-trained group had a higher central motor drive and power output compare to the recreational group. The endurance-trained group lower level of fatigue on the fatigue threshold caused less sensitivity of group III and IV afferents up to the brain and lead to higher CMD and performance compare to the recreational group (Amann & Dempsey, 2008; Amann et al. 2011, 2013; Hureau et al. 2014). The results show also a decrease in CMD and power output from test 1 to test 2 and higher CMD and power output in the 1 min TT compare to the 10 min TT that can be affected by biochemical changes in the muscle.

The results in table 1 show significant decrease in voluntary activation (VA) between the TT and the tests. A decrease in VA during or after sustained contractions shows a failure to drive the muscle and indicate central fatigue. This failure to drive the muscle caused by central fatigue reduce CMD down to peripheral muscles (Allen et al. 1998; Gandevia, 2001). The 10 min TT had a higher reduction in VA from baseline and a lower CMD than the 1 min TT. A study from Thomas et al (2015) show that TTs with longer duration develop a higher level of central fatigue and the results in our study found that 10 min TT with longer duration

develops more central fatigue than the 1 min TT with a shorter duration. The results show a reduction in VA also from test 1 to test 2 and means that test 2 ended with a higher level of central fatigue than test 1. This reduction in VA between the tests and TT contributed to a lower CMD and power output in test 2 and the 10 min TT compare to test 1 and the 1 min TT.

A bit surprising shows the EMG results for vastus lateralis in the 1 min TT a higher CMD from test 1 to test 2. The figure 4 and 5 show that power output change paralleled with changes in the CMD during the 10 min TT with a plateau and a sprint at the end. There was no parallel changes between CMD and power output during the 1 min TT, with an increase in CMD and a decrease in power output. A reason for increase of CMD between tests for vastus lateralis and no parallel changes between CMD and power output in the 1 min TT can be that the motor units compensate for higher level of peripheral fatigue with increase of CMD to maintain the power output (Enoka & Stuart, 1992). The 1 min TT was a short anaerobic conditions and the increase in CMD shows that the brain was able to send high level of CMD to try to maintain the power output. This indicated lower development of central fatigue in the 1 min TT and the decrease in power output in the 1 min TT was more affected by peripheral fatigue compare to the 10 min TT. These findings suggest that peripheral fatigue related to biochemical changes in the muscle (Enoka & Stuart, 1992) and central fatigue related to decrease in VA (Allen et al. 1998) was responsible for the decrease in power output and performance.

## **5.4 Conclusions**

A clear fatigue threshold in the anaerobic 1 min TT and an unclear fatigue threshold in the aerobic 10 min TT were found. The training status influence on the fatigue threshold and performance were the same for the anaerobic 1 min and the aerobic 10 min TTs where the endurance-trained group had lower fatigue level on the fatigue threshold compare to the recreational group. Speculate that this finding decrease the sensitivity of group III and IV muscle afferents up to the brain and explain the further results where the endurance trained had a higher CMD and performance than the recreational group. This supporting further evidence that the fatigue threshold affect the CMD and performance. The 1 min TT show a higher peripheral fatigue level on the fatigue threshold followed by higher CMD and power output compare to the 10 min TT and indicate that the peripheral fatigue had a higher influence on the anaerobic 1 min TT. These differences in the fatigue level between groups

and TTs indicate that the fatigue level on the fatigue threshold was task and condition specific. The results show increase of central fatigue from test 1 to test 2 and higher central fatigue in the 10 min TT compare to the 1 min TT. This indicate that central fatigue had a higher influence on the aerobic 10 min TT and longer duration developed higher level of central fatigue. These results show that quadriceps fatigue related to biochemical changes in the muscle and central fatigue related to decrease in VA was responsible for the fatigue threshold and decrease in performance. These findings show that training status have an influence on the fatigue threshold and performance where higher training status lead to lower level of fatigue on the fatigue threshold and higher performance. Further research have to study the trainings effect influence on fatigue threshold and performance with a training program over a period and compare results pre to post a training program to better determine the training effect on fatigue threshold and performance.

## 6 References

- Allen, G. M., Gandevia, S. C., & McKenzie, D. K. (1995). Reliability of measurements of muscle strength and voluntary activation using twitch interpolation. *Muscle and nerve*, 18, 593-600.
- Allen, G. M., McKenzie, D. K., Gandevia, S. C., (1998). Twitch interpolation of the elbow flexor muscles at high forces. *Muscle Nerve*, 21, 318-328.
- Amann, M., & Dempsey, J. A. (2008) Locomotor muscle fatigue modifies central motor drive in healthy humans and imposes a limitation to exercise performance. *Journal of Physiology*, 586(1) 161-173. doi: 10.1113/jphysiol.2008.141838
- Amann, M., Blain, G. M., Proctor, L. T., Sebranek, J. J., Pegelow, D. F., & Dempsey, J. A. (2011). Implications of group III and IV muscle afferents for high-intensity endurance exercise performance in humans. *Journal physiology* 589(21), 5299-5309. doi: 10.1113/jphysiol.2011.213769
- Amann, M., Yenturelli, M., Ives S. J., Mcdaniel, J., Layec, G., Rossman M. J. & Richardson, R. S. (2013) Peripheral fatigue limits endurance exercise via a sensory feedback-mediated reduction in spinal motoneuronal output. *Journal of applied Physiology*, 115, 355-364. doi: 10.1152/jappphysiol.00049.
- Amann, M. (2011) Central and peripheral fatigue: Interaction during cycling exercise in humans. *Medicine and Science in Sports and Exercise*, 43(11), 2039-2045 doi: 10.1249/MSS.0b013e31821f59ab
- Amann, M., Proctor, L. T., Sebranek, J. J., Peglow, D. F., & Dempsey, J. A. (2009) Opioid-mediated muscle afferents inhibit central motor drive and limit peripheral muscle fatigue development in humans. *Journal of physiology*, 587(1), 271-283.
- Amann, M., Blain, G. M., Proctor, L. T., Sebranek, J. J., Peglow, F. P., & Dempsey, J. A. (2010) Group III and IV muscle afferents contribute to ventilatory and cardiovascular response to rhythmic exercise in humans. *Journal of applied Physiology*, 109, 966-976. doi: 10.1152/jappphysiol.00462.2010
- Amann, M., Pegelow, D. F., Jacques, A. J., & Dempsey J. A. (2007) Inspiratory muscle work in acute hypoxia influences locomotor muscle fatigue and exercise performance of healthy humans. *American Journal of Physiology*, 293, 2036-2045 doi: 10.1152/ajpregu.00442.2007
- Borg, G. A. V., (1982) Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, 14, 377-381.
- Enoka, R. M., & Stuart, D. G., (1992) Neurobiology of muscle fatigue. Departments of physiology and exercise and sport sciences. *The American Physiological society*, 7567-7592

- Froyd, C., Millet, G. Y., & Noakes, T. D. (2013) The development of peripheral fatigue and short-term recovery during self-paced high-intensity exercise. *Journal of Physiology*, 591, 1339-1346.
- Gandevia, S. C., Allen, G. M., Butler, J. E., & Taylor, J. L. (1996) Supraspinal factors in human muscle fatigue: evidence for suboptimal output from the motor cortex. *Journal of Physiology*, 490(2), 529-536.
- Gandevia, S. C. (2001) Spinal and supraspinal factors in human muscle fatigue. *The American Physiological Society*, 0031-9333/01
- Hureau, T. J., Olivier, N., Millet, G. Y., Meste, O., & Blain, G. M. (2014) Exercise performance is regulated during repeated sprints to limit the development of peripheral fatigue beyond a critical threshold. *Experimental Physiology*, 99(5). DOI:10.1113/expphysiol.2014.077974
- Kufel, T. J., Pineda, L. A., & Mador, M. J., (2002). Comparison of potentiated and unpotentiated twitches as an index of muscle fatigue. *Muscle Nerve*, 25(3), 438–444
- Merton, P. A. (1954) Voluntary strength and fatigue. *Journal of Physiology* 123, 553-564.
- Sinoway, L., Shenberger, J., Leaman, G., Zelis, R., Gray, K., Baily, R., & Leuenberger, U. (1996) Forearm training attenuates sympathetic responses to prolonged rhythmic forearm exercise. *The American Physiological Society*, 0161-7567/96
- Thomas, K., Goodall, S., Stone, M., Howatson, G., St Clair Gibson, A., Ansley, L. (2015). Central and peripheral fatigue in male cyclists after 4-, 20-, and 40-km time trials. *Medicine and Science in Sports and Exercise*, 47(3), 537-46. doi: 10.1249/MSS.0000000000000448.