Six weeks of high intensity interval training with hyperoxia or normoxia in trained cyclists

- A polarized and periodized training approach

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Abstract

Aim
The main aim of this study was to investigate the longitudinal effects on cycling performance using a polarized and periodized scheme that was highly supervised and controlled. The second aim was to investigate the effect of using Hyperoxia. The questions used to address the aim were: (1) How does overall performance change after a six-week training intervention? (2) What is the time-course and pattern of performance changes to the training scheme? (3) How does the performance change within the groups?

Method
Nineteen male and female cyclists started the study (13 male and 6 female), however only 12 completed it (8 male and 4 female). The characteristics for the 12 subjects were: age (year) 33.6 ± 6.8, height (cm) 177 ± 9.1, body mass (kg) 73.4 ± 8.8. Using a randomized, double blind design, the test subjects were divided into hyperoxia (HOT) (n = 6) and normoxia (NOT) (n = 6) training groups. Over a six week period the subjects followed a controlled polarized periodization that included 15 high intensity interval training (HIIT) sessions (3 x 8 min, 3 x 8 + 4 min, 4 x 8 min & 4 x 4 min) on maximal sustainable intensity (isoeffort) on a cycle ergometer. The dosage of oxygen was administered intermittently by the oxelerate device. A 20 min all out test was performed as pre- and post test.

Results
The whole group (n = 12) increased mean power output (W) by 6.4 % (P = 0.002). The relative power output (W/kg) increased significantly 8.2 % (P = 0.0011). The HOT group (n = 6) increased their power output by 8.3 % (P = 0.028) and their relative power output increased by 9.4 % (P=0.011). The whole group (P = 12) significantly increased their VO_{2\text{mean}} by 4.1 % (P = 0.03) and in the relative value by 5.4 % (P = 0.01) on the 20 min all out test. The whole group also had a significant increase in VO_{2\text{peak}} of 3.7 % (P = 0.04). A very strong correlation could be found between the training data and the performance test.

Conclusions
The training intervention was favourable for increasing performance and VO_{2\text{peak}} in cycling. Usage of hyperoxia during the training intervention increases the performance.
Sammanfattning

Syfte och frågeställningar

Huvudsyftet med denna studie var att undersöka de longitudinella effekter på prestation i cykling med hjälp av ett polariserat och periodiserat träningsupplägg som var väl övervakat och kontrollerat. Det andra syftet var att undersöka effekten av att använda hyperoxi. De frågeställningar som hjälpte att besvara syftet var: (1) Hur förändras prestationen efter en sex veckors träningsintervention? (2) Hur anpassar sig försökspersonerna till träningsschemat över tid? (3) Hur förändras prestationen inom grupperna?

Metod

19 manliga och kvinnliga cyklister deltog i studien (13 manliga och 6 kvinnliga), 12 fullföljde hela studien (8 manliga och 4 kvinnliga). Karaktäristiken för de 12 försökspersonerna var: ålder (år) 33.6 ± 6.8, längd (cm) 177 ± 9.1, vikt (kg) 73.4 ± 8.8. Försökspersonerna delades in i hyperoxi (HOT) (n = 6) och normoxi (NOT) (n = 6), studien var dubbelblind. Under sex veckor följde försökspersonerna en kontrollerad polariserad periodisering som inkluderade 15 högintensiva intervallträningspass (HIIT) (3 x 8 min, 3 x 8 + 4 min, 4 x 8 min & 4 x 4 min) på högsta genomförbara intensitet (isoeffort) på cykelergometer. Doseringen av syre administreras intermittent genom Oxelerate-enheten. Ett 20 min all-out test utfördes som för- och eftertest.

Resultat

Hela gruppen (n = 12) ökade signifikant på prestationstestet (W) med 6.4 % (P = 0.002). Den relativa effekten (W/kg) ökade signifikant med 8.2% (P = 0.0011). HOT (n = 6) ökade signifikant på prestationstestet med 8.3% (P = 0.028) och den relativa effekten ökade med 9.4% (P = 0.011). Hela gruppen (n = 12) ökade signifikant i VO_{2medel} under prestationstestet med 4.1 % (P = 0.03) och i det relativa värdet med 5.4 % (P = 0.01). Hela gruppen hade också en signifikant ökning av VO_{2peak} med 3.7 % (P = 0.04). En mycket stark korrelation hittades mellan träningsspassdata och prestationstestet.

Slutsats

Träningsupplägget är gynnsamt för ökning av prestation och VO_{2peak} i cykling. Användning av hyperoxi under träningsupplägget ökar prestationen.
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1 Introduction

Researchers and coaches have always tried to optimize training methods in order to increase athlete’s performance. Endurance athletes have historically used altitude training (hypoxia) in order to improve their performance, but is it also possible that the opposite, hyperoxia, could be beneficial for performance improvements? In particular, what happens when hyperoxia is combined with high intensity interval training (HIIT) in a polarized and periodized manner using power meters to control the training load?

1.1 Background

Research on hyperoxia training (inspiration of >20.94 % oxygen) has been made since May 1954, when Sir Roger Bannister ran the first English mile under four minutes. In the December of that year, he published a paper showing that the use of hyperoxia during a ‘time to exhaustion’ test had significantly increased the performance. As to whether Bannister used hyperoxia during his training sessions is still unresolved, but the suspicions remain. Of certainty is the fact that he ran the dream mile without supplemented oxygen, which was a big achievement back then. (Bannister & Cunningham 1954; Bannister, Cunningham & Douglas 1954)

HIIT emerged in Sweden in the 2010s. Tabata, Nishimura, Kouzaki, Hirai, Ogita, Miyachi and Yamamoto (1996) published a paper saying that short HIIT had a beneficial effect on Olympic speed skater performance. This article is often referred to in popular media and has influenced the “boom” in which new variations of HIIT emerge on a regular basis. The type of HIIT that they described is not the same as in the present study, where longer bouts (≥4 min) of HIIT were used. However, within endurance sport circles, HIIT has always been an obvious part of training. The challenge for endurance sport is how to optimize periodization in the training regimen.

In cycling, the use of power meters instead of heart rate monitors for adjusting intensity in training has become more common. Professional cyclists have used this method for some time, but now competitive and recreational cyclists are also using it to their benefit as reduced costs have led to more widespread usage. When comparing power output figures between people, a relative value (W/kg) is preferred since it takes body mass into account. During a 20
min all out test, a professional cyclist can produce around 6.5 W/kg and a competitive cyclist around 4 - 5 W/kg (Pinot & Grappe 2015).

1.1.1 Gas mixtures

Hyperoxia is a condition were the body is exposed to higher partial pressures of oxygen (O₂) than normally encountered breathing air at sea level. It often refers to breathing a gas mix that has a higher concentration of O₂ (>20.94 %) than normal air at sea level. Hyperoxia can also be achieved by increasing the partial pressure of oxygen (PO₂) in a hyperbaric chamber for example. Normoxia refers to the normal composition of air that we breathe (78.08 % nitrogen (N), 0.94 % noble gases, 0.04 % carbon dioxide (CO₂), and 20.94 % oxygen).

1.1.2 Oxygen Saturation

Arterial oxygen saturation (SaO₂) can affect aerobic capacity because of the desaturation that occurs when the body is exposed to hard aerobic stress (Bassett & Howley 2000). At rest, mean SaO₂ is ~ 97.90 - 98.64% (Goldberg, Buhbut, Mimouni, Joseph & Picard 2012; Nielsen, Madsen, Svendsen, Roach & Secher 1998). There is a linear relationship between the work percentage at VO₂max and SaO₂, and the higher the percentage of VO₂max, the more the desaturation. In ~20% of endurance athletes, SaO₂ at peak exercise can fall to 92% or lower, which is referred to as exercise-induced hypoxemia (EIH). In well trained athletes working at 100 % of VO₂max in normoxia, a mean SaO₂ of ~90.6% could be recovered to ~95.9% by breathing a hyperoxic gas mixture (26% O₂) (Bassett & Howley 2000). A similar response has been shown in women where SaO₂ increased from 91.6 (± 0.6%) (normoxia 21% O₂) to 96.8 (± 0.1%) (hyperoxia 26% O₂) during a maximal oxygen uptake test (Harms, McClaran, Nickele, Pegelow, Nelson and Dempsey 2001).

Similar effects were shown by a study carried out in Finland, where they monitored SaO₂ during intervals of 3 x 3 x 300 meters on a treadmill with nine 400 meter male sprinters competing at Finnish national level. There was a significant (P <0.05) difference in oxygen saturation when runners ran at 83% of their seasonal best times over 400 m. For normoxia the mean SaO₂ was 88.7% while for hyperoxia (40% O₂) it was 95.9%. (Nummela, Hämäläinen & Ruusko, 2002) In many studies, SaO₂ is mentioned as the variable that has the greatest correlation to performance and VO₂max improvement between hyper- and normoxia. The amount of desaturation that occurs during exercise among fit males and females is specific to the individual. (Harms et al. 2001)
1.2 Previous Research

Review of previous research has focused on six topics:

1. Effects on VO$_{2\text{max}}$ using hyperoxia
2. Effects on performance using hyperoxia
3. Longitudinal effects of hyperoxia in training
4. Effects of HIIT
5. Training load
6. Training schedule

1.2.1 Acute effects on VO$_{2\text{max}}$ using hyperoxia

It has been well established that hyperoxia increases VO$_{2\text{max}}$, but it is still unresolved as to which level of O$_2$ would give the largest increase in comparison to a normoxic VO$_{2\text{max}}$. Previous studies have used from 26 - 100% O$_2$ and suggest that there is a non-linear effect, depending on the percentage of O$_2$ inhaled.

Studies that used 26 % O$_2$ showed a 6.6 % and 6.3 % increase in VO$_{2\text{max}}$ respectively (Powers, Lawler, Dempaey, Dodd & Landry 1989; Harms, McClaran, McClaran, Nickele, Pegelow, Nelson & Dempsey 2001). Breathing 100 % O$_2$ increased VO$_{2\text{max}}$ by 8.1 % (Margaria, Camporesi, Aghemo & Sassi 1972; Knight, Schaffartzik, Poole, Hogan, Bebout & Wagner 1993), while 50-62 % O$_2$ increased VO$_{2\text{max}}$ by 11.1-12.6 % (Ekblom, Huot, Stein & Thorstensson 1975; Plet, Pedersen, J. & Hansen 1992; Peltonen, Rantamäki, Nittymäki, Sweins, Viitasalo & Rusko 1995). The largest effect was noted when the inspired gas contained 30-32 % O$_2$, with the VO$_{2\text{max}}$ increasing by 13-14.4 %; these tests used either a cycle or rowing ergometer. (Peltonen, Tikkanen & Rusko 2001; Nielsen, Madsen & Svendsen 1998)

1.2.2 Acute effects on performance using hyperoxia

Based on previous studies, acute performance using hyperoxia increases performance significantly. The studies below used a cycle or rowing ergometer when measuring the effect of hyperoxia during a performance test. Studies conducted from 1970 to 1990 report that during time trial tests, the performance increase was between 15-31 % (Margaria et al. 1972; Fagraeus, Hesser & Linnarsson 1974; Adams & Welch 1980; Buick, Gledhill, Froese & Spriet 1980; Wilson, Welch & Liles 1975; Hogan, Cox & Welch 1983). Articles from 1990 onwards show an increase in performance on a time trial test of 32.3 – 57.0 % (Plet et al.)
In peak workload and all out tests the increase in performance is slightly smaller at between 3.2-8.7 % (Hogan, Cox & Welch 1983; Powers et al. 1989; Knight et al. 1993; Peltonen et al. 1995; Peltonen, Rusko, Rantamäki, Sweins, Nittymäki & Viitasalo 1997; Nielsen, Madsen & Svendsen 1998; Peltonen, Tikkanen & Rusko 2001).

1.2.3 Longitudinal effects of hyperoxia in training

The effect of hyperoxic versus normoxic training on cycle ergometers over time has been studied and the results are equivocal. Some authors believe that training with hyperoxia over time is unnecessary, while others argue that it provides a greater training effect. Kilding, Wood, Sequira and Benetti (2012) conducted a training study in which 16 trained cyclists exercised in hyperoxia (60 % O₂) or normoxia (21 % O₂) for two high-intensity interval sessions a week over a four week period. The results of this study showed that the effect of hyperoxia did not have any advantages over training with normoxia on power output. The authors claimed that it might be less effective to use hyperoxia during exercise (Kilding et al. 2012).

A training study from 2005 comparing normoxic vs. hyperoxic training, reported that the hyperoxic group achieved a greater (P <0.05) improvement in performance than the normoxic group. The authors suggested that the higher power output during the training sessions with hyperoxia might have increased the muscular mitochondrial capacity more than during normoxia. (Perry, Reid, Perry & Wilson 2005) In a follow-up study, Perry, Talanian, Heigenhauser and Spriet (2007) divided nine participants into a hyperoxic group (60 % O₂) and a normoxic group. Over a six week intervention they trained three times a week 10 x 4min at maximal sustainable intensity (isoeffort) on cycle ergometers. Both groups had significant (P <0.05) improvements in VO₂max and performance (time trial test), however there was no difference between hyperoxic and normoxic groups. The only difference between the groups was that the power output on the training sessions was significantly higher in the hyperoxic group (P <0.05). (Perry et al. 2007)

In a Finnish study (Hämäläinen, Ikka Nummela & Ruusko 2000), sixteen national level male runners significantly increased their performance while training with hyperoxia (30 % O₂). Half of the subjects trained with hyperoxia and half with normoxia. The intervention took
place over four weeks, with three training sets a week. Over a 3000 m time trial, the hyperoxic subjects reduced their time from 9:55.1 ± 42.4 to 9:39.6 ± 35.9 (3.8 %) (P <0.05). There was no change in VO$_{2\text{max}}$ during the intervention. The authors concluded that the increase in performance for the hyperoxic group was due to the higher workload. (Hämäläinen, Ikka Nummela & Ruusko 2000) Based on these collective studies, there is evidence for an improvement in performance with hyperoxic training, however, the mechanism does not appear to be mediated by an increase in VO$_{2\text{max}}$.

1.2.4 High intensity interval training (HIIT)

In interval training there are two main parameters that should be considered: duration and intensity, which are instigated for the purpose of increasing performance. Seiler, Jøranson, Olesen and Hetlelid (2013) compared three different cycle ergometer interval designs that included, 4 x 16 min, 4 x 8 min and 4 x 4 min at isoeffort. The 4 x 8 min resulted in a greater overall gain in VO$_{2\text{peak}}$ (+8.5 %), power at VO$_{2\text{peak}}$ (+8.5 %), power at 4 mmol/L lactate (+16.2 %) and time to exhaustion (+91.1 %). The mean heart rate (HR) was at 90 % of HR$_{\text{peak}}$ during the 4 x 8 min intervals. (Seiler et al. 2013)

Sandbakk, Sandbakk, Ettema and Welde (2012) compared the effect of short intervals (n = 7) (2-4 minutes isoeffort) with longer intervals (n = 7) (5-10 minutes isoeffort) for an eight-week training intervention. National level Norwegian male and female cross country skiers with a VO$_{2\text{mean}}$ of 67.4 ± 7.7 ml min$^{-1}$kg$^{-1}$ performed the study. VO$_{2\text{max}}$ increased significantly (P <0.05) for both groups (3.7 %), but endurance performance and ventilatory threshold only significantly (P <0.05) increased for the long interval group. (Sandbakk et al. 2012)

1.2.5 Training load

In the present study, all of the test subjects were scheduled to do the same amount of training, but the impact of the training has individual differences. Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal and Dodge (2001) validated “A New Approach to Monitoring Exercise Training”, defining a methodology that uses a calculation of duration (minutes) and the RPE (1 - 10 scale) of the training session to give the “training load”. The training load number does not have an appreciable meaning in isolation, but when used over time it is a good indicator of the total training load. This gives an indication of what can be expected from the athletes in the form of adaptation to training as well as progression betweenpre- and post tests. (Foster et al. 2001)
1.2.6 Periodization

One of the keys to good progression in training is to have proper periodization. The training variation is an important component if the aim is to develop good performance progression. The variation and progression can also help to prevent monotony which can lead to overtraining. (Kiely 2012)

Stöggl and Sperlich (2014) compared four different classic training periodization models during a nine week intervention; they included high volume, threshold, polarized and HIIT. The polarized periodization improved VO$_{2_{peak}}$ (4.4-4.6 L/min), Time to exhaustion (TTE) (+17.4 %) and power at VO$_{2_{peak}}$ (+5.1 %) more than the other models. An increase in power at 4 mmol/L was shown in both the polarized- (8.1 %) and HIIT (5.6 %) periodization. The authors concluded that a polarized periodization showed the biggest impact on key variables of endurance performance in well-trained athletes. Their polarized model included three blocks lasting three weeks. The first two weeks included two 60-minute HIIT-sessions, (4 x 4 min, 2 min rest) two low intensity sessions (150-240 min which included six to eight five second sprints at maximal intensity) and two 90-minute low intensity sessions. The last week was a recovery week that included one 60-minute HIIT session (4 x 4 min, 2 min rest), one 120-180 minute low intensity session and one 90-minute low intensity session. (Stöggl & Sperlich 2014)

Laursen (2010) also supported the polarized approach in training for endurance athletes, but believed that further research is needed to know how to best to organize the training in which more empirical data is collected from coaches and athletes. (Laursen 2010)

1.3 Conclusion of previous research

The acute studies investigating VO$_{2_{max}}$ and performance show gains will be made when breathing a hyperoxic gas. The highest gain in performance was when using gas mixtures containing around 30 % O$_2$. The effect of the longitudinal use of hyperoxia appears to be uncertain. However, it is established that longer HIIT sessions have a better effect on endurance performance than short ones, and that a polarized training model should be used.
1.4 Aim and research questions

The first aim of this study was to investigate the longitudinal effects on cycling performance using a polarized and periodized scheme that was highly supervised and controlled. The second aim was to investigate the effect of using Hyperoxia.

Research questions

- How does overall performance change after a six-week training intervention?
- What is the time-course and pattern of performance changes to the training scheme?
- How does the performance change within the groups?

2 Methods

2.1 Subjects

Subjects were recruited on campus and via contacts to reach cyclists with a self-reported high training load in hours per week. The aim was to include those that possibly had reached a training plateau in their regular daily schedule, and not for a specific VO2 cut off. A selection round was conducted before the start of the preliminary tests, in order to pick out the best suited subjects and to familiarise them with the test procedures. This consisted of a submaximal and maximal test on a cycle ergometer. Following the selection round, nineteen competitive cyclists and triathletes (13 male, 6 female) were recruited to participate in the study. Of the nineteen recruited, only twelve subjects (8 male, 4 female; 24 - 47 years) completed the study and met all of the inclusion criteria during the training intervention.

Previous studies suggest that the physiological response and impact on endurance training are not affected by gender or this age range (Skinner, Jaskolski, Jaskolska, Krasnoff, Gagnon, Leon, Rao, Wilmore & Bouchard 2001). Pre-intervention characteristics of the twelve subjects are presented group wise in Table 1.

Informed written consent was provided by all subjects before participation. The subjects were also informed that they could withdraw from the study at any point without giving any further reason. All the subjects in this study are anonymous. After the end of the study, the subjects were given their own personal test and training data. The study was approved by the regional ethical review board and designed according to the declaration of Helsinki. This study has taken into consideration the four key requirements for research ethics (the information,
consent, confidentiality and use requirements) according to the research methodology bases
(Patel & Davidson 2011, p. 64).

Four subjects dropped out from the study due to compliance issues; they performed extra
training or competed during the training intervention period although they had been asked not
to do so. Two subjects withdrew due to health issues and one subject aborted the study.

Table 1 - Characteristics of subjects at inclusion. Hyperoxic training group (HOT) and normoxic training group
(NOT). Values are mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>HOT (n = 6)</th>
<th>NOT (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n = )</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Female (n = )</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Age (years)</td>
<td>32.8 ± 8.0</td>
<td>34.4 ± 6.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.5 ± 8.6</td>
<td>180.4 ± 8.9</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>72.9 ± 12.0</td>
<td>73.8 ± 6.0</td>
</tr>
</tbody>
</table>

2.2 Design

The present study was designed as a double blind experimental trial with two groups matched
for pre-intervention characteristics. All tests and training interventions were performed at the
Swedish School of Sport and Health Sciences (GIH) in the laboratory of applied sport science
(LTIV) between March and May 2015. The subjects were divided into two groups, hyperoxic
training (HOT) or normoxic training (NOT). The two groups performed a polarized training
program consisting of HIIT-sessions of varying kinds combined with additional low-intensity
training sessions. Over the six week intervention period the subjects performed a total of 15
HIIT-sessions each (varying from 1 to 3 a week) plus additional low intensity sessions (1 to 2
a week). They also performed a performance test pre and post the training intervention.

2.3 Materials

During the performance test oxygen uptake was measured with a Jaeger Oxycon Pro
(CareFusion, GmbH, Hoechberg, Germany) in mixing chamber-mode. The measurements
included oxygen uptake (VO$_2$), carbon dioxide production (VCO$_2$), respiratory exchange ratio
(RER), ventilation (VE), breath frequency (BF) and fraction of expiratory oxygen and carbon
dioxide (FEO$_2$, FECO$_2$). The subjects wore a 7450 series V2 mask with headgear connected
to a 2730 two-way Y-shape non-rebreathing valve (Hans Rudolph inc, Kansas, USA) and a
tube of length 150 cm by 4 cm in diameter. The Oxycon Pro was started up 30 min before
each test in order to let it warm up properly. After that, a calibration was performed on
ambient conditions, volume and gas. The gas sensors were calibrated via an automated process using a certified calibration mixture (15.00 % O₂, 5.999 % CO₂, Air Liquide, Paris, France). For volume and gas sensors, calibration procedures were repeated until variations were < 1 % between previous and current settings. The validity of the Oxycon Pro system and the stability of its measurements have been reported to be high in previous studies (Rietjens, Kuipers, Kester & Keizer 2000; Foss & Hallén 2004).

All of the training sessions and performance tests were performed using mechanically braked Monark LT2 cycle ergometers (Monark Exercise AB, Vansbro, Sweden). The Monark LT2 uses a potentiometer for measuring power output, which they call "Sprint Power Resistance" (SPR). The workload is adjusted manually from the handlebar via a lever, like a gearbox. The force goes up to 7 kilopond (KP), giving a range from 0 - 1400 watts (W) if pedalling up to a cadence of 200 RPM; changes can be made from 0 - 7 KP within a second. A screw on the lever allows fine tuning of the power output by as little as 1 W increments. The ergometer is specifically designed to be a training machine for athletes. In order to get the power output data, the ergometer was connected to a computer (PC) via an USB cable, and used with Monarks own software (Monark All-In-One Analysis Software, version 1.0.14.0). The data was recorded every second, and then exported and analyzed in Excel (Microsoft Corporation, Redmond, Washington, USA).

In order to administer oxygen or air to the subjects, 50 L gas tanks were used with mixtures of either 100 % oxygen (O₂) for hyperoxic conditions or regular air for normoxic conditions (nitrogen (N₂) 78.09 %, oxygen (O₂) 20.94 %, argon (Ar) 0.93 %, carbon dioxide (CO₂) 0.04 %) (Air Liquide, Paris, France). The gas tanks were connected to a device, Oxelerate ver. 1.1 (Oxelerate AB, Tumba, Sweden), that administered the O₂ / air intermittingly to the subjects. The subjects only received O₂ / air during the inspiration cycle as the Oxelerate could detect when an inspiration started and then administered the gases. The Oxelerate was connected to a computer via a USB cable and used with the Oxelerate software (ver. 2.5). The software recorded the flow data and it was possible to adjust the flow settings. The pre-settings of the Oxelerate were for 18 L / min gas administration and a valve timing of 0.6 seconds. The subjects wore a slightly modified MSA Advantage 200LS mask (MSA, Cranberry Township, Pennsylvania, USA) to receive either the hyperoxic or normoxic gases. For hyperoxia, the inspiratory oxygen concentration level (FiO₂) was 26 – 30 % when mixed during inspiration with room air, according to previous calculations using the Oxelerate (Boberg 2012).
For all lactate and glucose measurements a Biosen C-Line Clinic (EKF-diagnostics, GmbH, Barleben, Germany) was used to analyse the samples. A capillary micro-sample (20 µl) was collected from the fingertip and then put in a pre-filled reaction cup containing a hemolyzing solution of 1 ml (EKF safe-lock). Only the lactate values will be submitted in the results.

For heart rate measurements, Polar H1 heart rate sensors with Polar soft straps were used (Polar Electro Oy, Kempele, Finland). Initially ANT+ sensors were used, however the output signal was too strong so they interfered with Polars signal and took over.

2.4 Performance test

For this study, a 20 min all-out test on a cycle ergometer was used as the primary measurement of performance pre and post the training intervention with measurement of both power output and VO$_2$. A 20 min all-out test is commonly used as a performance measure for cyclists and is also referred to as functional threshold power (FTP) in the literature (Allen & Coggan 2010 p. 61). The performance test was conducted around a week before and after the training intervention. This type of time trial protocol, whereby a fixed time or distance is utilised, appear to be more reliable and reproducible than others, and convey significant advantages for studying endurance exercise performance (Jeukendrup, Saris, Brouns & Kester 1996; O'Brien & O'Connor 1999; Doyle & Martinez 1998). Many of the subjects were used to this test and had performed it prior to the start of this study.

The test took place at the LTIV in a climatic controlled room. The temperature and humidity were set to 19°C and 40% respectively throughout the test. The subjects body mass was noted before the test. The 20 min all-out test was conducted on a Monark LT2 cycle ergometer, as previously described. Seat and handlebar position was adjusted individually by the subjects according to their own preferences, and they used their own cycling shoes and pedals (in some cases). A standardized warm-up protocol of 20 min was used, based on Borg’s 6-20 RPE-scale (Borg 1982) (see Appendix 2 for details); it was trialled in several pilot tests beforehand. The subjects were familiarized with the ergometer during the warm-up and were told to find a suitable gear that they would start the test with. During the last five minutes of the warm-up, they wore the mask with headgear to measure VO$_2$ throughout the test. After the warm-up finished, the subjects were counted down into the start of the test, with the commands: "10 seconds, 5 seconds, 3, 2, 1, go".
The subjects were blinded to the test conditions and did not see any data / numbers except for cadence during the test. They were told their test results only after the whole study was completed. The subjects paced themselves during the test, which meant that they adjusted the resistance as they wished. Prior to the test, they were told that they should aim to reach as high a mean power output as possible during 20 minutes. They received motivational feedback and information on the time left (the subjects had a digital clock in front of them). They were instructed to be seated during the test, and if necessary, stand up and sprint during the last 30 seconds. After the 20 minutes was completed, the subjects had to remain still for three minutes on the bike with no pedalling and the mask on. Directly afterwards, they took off the mask and rated their exertion both central (breathing) and local (legs) with Borg's 6 - 20 RPE scale. Lactate and glucose samples were taken from the fingertip of their left hand after one minute and three minutes, then they were allowed to cool down.

The VO2-data was analysed with five second-logging, and mean values were taken from the whole 20 minutes and maximal values from the highest consecutive 60 seconds within that file. The data from the cycle ergometer was logged every second and included power output (W), cadence (rpm) and heart rate (bpm).

2.5 Training intervention

2.5.1 Distribution of training

The subjects came to the laboratory during a six-week intervention period where they performed strictly monitored HIIT. During these six weeks, there were a total of 15 HIIT-sessions accompanied by longer, low-intensity sessions that the subjects performed on their own (a so-called polarized training model as described previously). The low-intensity sessions consisted of five LOW1 (2.5 hours) and six LOW2 (4 hours) with the intensity being <75 % of HRmax. During LOW1 the subjects had to cycle during the whole session, either outdoors or on a stationary bike indoors. During LOW2 the subjects could combine cycling with other activities such as running, using a cross trainer or indoor rowing as long as it was continuous. The LOW2 sessions were scheduled for the weekend, so that the subjects had the time to put in the hours of training. The subjects could freely choose for themselves on which day during the weekend that they did LOW2. During the other days of the week, the subjects could perform low intensity recovery training that did not lead to extra fatigue. For a schematic design of the training intervention, see Figure 1.
In order to meet the inclusion criteria, an adherence rate of 85% was mandatory. This meant fulfilment of 13 of 15 HIIT sessions, four out of five LOW₁ and five out of six LOW₂ sessions. Beyond these fixed sessions, the subjects could perform lighter core strength sessions, but not use their legs. The subjects was also instructed to fill out a web-based training log with all their sessions during the intervention.

The six week intervention protocol used a periodization model with a relationship of 2:1 between hard weeks and easy weeks; see Figure 1. As stated in the Background, a periodization of training distribution has been shown to be more beneficial than a traditional model in order to reach peak performance. During week 3 and 4 there was also a periodization within the week, with harder HIIT sessions on monday and friday, and "easier" sessions (less volume) on wednesday. Both the HIIT sessions volume and the total volume per week progressed during the intervention period (not in easy weeks) in order to push physical limits and to avoid stagnation; see Figure 2.

![Figure 1 - Schematic design of the training intervention](image-url)
2.5.2 Description of a HIIT-session

All of the HIIT-sessions, regardless of interval type, had the same model of structure. Here follows a detailed description of a session.

On arrival at the laboratory, the subjects immediately filled out a questionnaire (see Appendix 3) recording their mood and level of fatigue during the last 24 hours. From this information the supervisors could adjust the load and draw conclusions about their performance. Before every session their weight was recorded and a resting lactate/glucose sample was taken from the fingertip. The subjects were then assigned an ergometer and made their adjustments regarding seat post height and stem length. They used their own cycling shoes (SPD cleats) and in some cases pedals also. Four ergometers were lined up next to each other in pairs, and in front there was a large screen with a digital clock counting up for them to watch. Immediately in front of the ergometers sat computers and Oxelerates. Both the ergometers, computers and Oxelerates were marked with a number (1 to 4) to maintain continuity of use. The Oxelerates were connected to gas tubes that were located in a closed locker behind the ergometers. Every subject in a session started training at the same countdown, while the warm-up procedure was standardized and was the same as the one used in the performance test; see Appendix 2. The temperature in the room was between 19 - 21°C, and every subject had a fan right next to them for cooling.
With 30 seconds to go until the start of an interval, the subjects put on the mask that was connected to the Oxelerate. At the end of an interval, a countdown was commenced as follows: 1 minute...30 seconds...10 seconds...5...3, 2, 1, stop. On stopping, the subjects took of their mask immediately (meaning no gas mixtures were inhaled during the rest period), they were asked their RPE score for their legs and breathing, and a lactate/glucose sample was taken from their fingertip. The rest periods were active, meaning that the subjects pedalled lightly. After the last interval, a 10 minute cool down was performed. When the cool down was finished and the subjects got off the ergometers, they were asked for their RPE score for the whole session with a number between 0 - 10, see Appendix 4. That number was then multiplied by the total duration of the session in minutes, resulting in an exercise score called TRIMP (training impulse) (Foster et al. 2001). During the intervals the subjects received verbal encouragement in order to perform the best they could on that day.

The subjects were blinded from the data during the sessions, meaning that they did not know what power output, heart rate, lactate and glucose they had posted. The only thing they could see was their cadence. Supervisors saw the live data from power output and heart rate and so could adjust the power output during the intervals to maintain work at the isoeffort level. The goal was to achieve as high a mean power output as possible, so from one session to another the supervisors checked the previous values and started the session at a similar power output. In this way, power output could be more controlled with less risk of the subject crashing on the first interval and improving overall performance. The RPE scores were also taken into consideration when adjusting the intensity. This was thought to be a better training model, with the supervisors acting more like personal coaches for the subjects, with full insight to their training data.

### 2.6 Validity and reliability

Before the start of the study, the oxygen uptake measurement unit (Jaeger Oxycon Pro) was validated against the Douglas bag method which is considered to be gold standard for metabolic measurements (Rosdahl, Lindberg, Edin & Nilsson 2012). The measurement error of the Jaeger Oxycon Pro was 3 %.

Regarding the lactate and glucose measurements, the Biosen was calibrated automatically every 60 min using a pre-filled multi standard solution of 12 mmol/L with a measurement error of 1.5 %. A linearity test-kit with standard solutions of 2 (1.80-2.20), 7 (6.75-7.25) and
18 (17.50-18.50) mmol/L was also used in order to assess the validity of the machine, limit values in brackets.

The Monark LT2 cycle ergometers were calibrated according to the manufacturer’s instructions continuously throughout the study. The ergometers were also calibrated with the Ergometer Calibrator, model 17801 (VacuMed, Vacumetrics Inc, Ventura, California, USA) for a range between 50 - 400 W; this showed that the Monarks were 5.1 % lower in power output. This is because the Monark ergometer measures the power output in the flywheel which leads to friction of 4 - 5 % in comparison to measurement of power output at the crankshaft (for example SRM-systems), as stated by Monark.

**2.7 Statistics**

All of the statistics were performed in Microsoft Excel 2013 (Microsoft Corporation, Redmond, Washington, USA). To test the level of significance, a Student's $t$-test (paired two sample $t$-test) was conducted. The level of significance was set to $P < 0.05$. For mean values the function MEAN in Excel was used, and the standard deviation was been calculated using the function STDEV ($\sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$) that represents a measure of the amount of variation around a set of data values mean value.
3 Results

The whole group (n = 12) significantly increased their mean power output from 303 ± 59 W to 323 ± 51 W (P = 0.0020), see figure 3. The relative power output increased significantly from 4.12 ± 0.55 W/kg to 4.46 ± 0.41 W/kg (P = 0.0011), see figure 4.

The whole group (n = 12) significantly increased their VO\textsubscript{2mean} from 3.78 ± 0.72 L/min to 3.93 ± 0.74 L/min (P = 0.03) and in the relative value from 51.4 ± 6.1 ml/kg/min to 54.1 ± 5.3 ml/kg/min (P = 0.01). The whole group also had a significant increase in VO\textsubscript{2peak} (P = 0.04), expressed in relative values, from 56.1 ± 6.8 to 58.1 ± 5.9 ml/kg/min. No significance was found in absolute values of VO\textsubscript{2peak}. Data from the performance test (pre/post) see table 2.
Table 2 - All data from performance test on whole group pre- and post test
(asterix indicates significant result)

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>73.3 ± 8.8</td>
<td>72.2 ± 8.9*</td>
</tr>
<tr>
<td>HRmean (1/min)</td>
<td>178.0 ± 9.3</td>
<td>177.4 ± 9.0</td>
</tr>
<tr>
<td>RPE (L)</td>
<td>19.3 ± 0.9</td>
<td>19.7 ± 0.7</td>
</tr>
<tr>
<td>RPE (B)</td>
<td>19.1 ± 0.8</td>
<td>19.5 ± 0.7</td>
</tr>
<tr>
<td>VO2peak (L/min)</td>
<td>4.13 ± 0.82</td>
<td>4.27 ± 0.74</td>
</tr>
<tr>
<td>VO2mean (L/min)</td>
<td>3.78 ± 0.72</td>
<td>3.93 ± 0.74*</td>
</tr>
<tr>
<td>VO2peak (ml/kg/min)</td>
<td>56.1 ± 6.8</td>
<td>58.1 ± 5.9*</td>
</tr>
<tr>
<td>VO2mean (ml/kg/min)</td>
<td>51.4 ± 6.1</td>
<td>54.1 ± 5.3*</td>
</tr>
<tr>
<td>RERmax</td>
<td>1.09 ± 0.04</td>
<td>1.08 ± 0.03</td>
</tr>
<tr>
<td>RERmean</td>
<td>1.01 ± 0.02</td>
<td>1.03 ± 0.02*</td>
</tr>
<tr>
<td>VEmax (L/min)</td>
<td>160.1 ± 32.6</td>
<td>159.4 ± 36.2</td>
</tr>
<tr>
<td>VEmean (L/min)</td>
<td>127.7 ± 20.8</td>
<td>133.3 ± 24.1</td>
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<tr>
<td>BFmax (1/min)</td>
<td>60.8 ± 7.8</td>
<td>59.8 ± 8.9</td>
</tr>
<tr>
<td>BFmean (1/min)</td>
<td>45.2 ± 4.2</td>
<td>45.7 ± 5.1</td>
</tr>
<tr>
<td>Power outputmax (W)</td>
<td>278.1 ± 58.8</td>
<td>295.8 ± 5.5*</td>
</tr>
<tr>
<td>Power outputmean (W/kg)</td>
<td>3.78 ± 0.55</td>
<td>4.09 ± 0.41*</td>
</tr>
<tr>
<td>Cadence,mean (rpm)</td>
<td>96.7 ± 6.7</td>
<td>99.4 ± 4.7</td>
</tr>
<tr>
<td>Lactate(max (mmol/L)</td>
<td>13.50 ± 2.7</td>
<td>13.91 ± 2.1</td>
</tr>
</tbody>
</table>

A very strong correlation could be found between the training data (mean power output on all of the training sessions) and the performance test (mean power output), and the correlation increased from pre- to post test. The whole group had an R²-value of 0.92138 from the pre test and R²-value 0.97253 from the post test, see figure 5 and 6.

Figure 3 - Correlation between performance test pre and the mean power output (W) from HIIT-sessions

\[ R^2 = 0.9214 \]
Figure 4 - Correlation between performance test post and the mean power output (W) from HIIT-sessions

A progression could be seen for the relative power output (W/kg) and training impulse (TRIMP) during the HIIT-sessions throughout the training intervention for both the HOT and NOT group, see figure 7.

Figure 5 - Mean power output (W/kg) and TRIMP-score from HIIT-sessions on whole group
The HOT (n = 6) group significantly increased their power output from 263 ± 49 W to 285 ± 47 W (P = 0.028), see figure 8. The relative power output increased from 3.62 ± 0.33 W/kg to 3.96 ± 0.21 W/kg (P = 0.011), see figure 9. NOT (n = 6) did not significantly increase in power output or relative power output. Group data from the performance test (pre/post) see table 3.

![20 minutes all out NOT vs. HOT (W)](image1)

Figure 6 - Performance test mean power output (W) between groups pre- and post test (asterix indicates significant result)

![20 minutes all out NOT vs. HOT (W/kg)](image2)

Figure 7 - Performance test mean power output (W/kg) between groups pre- and post test (asterix indicates significant result)
Table 3 - All data from performance test groupwise pre- and post test (asterix indicates significant result)

<table>
<thead>
<tr>
<th></th>
<th>HOT (n = 6)</th>
<th>POST</th>
<th>NOT (n = 6)</th>
<th>POST</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>72.8 ± 11.8</td>
<td>71.9 ± 11.4</td>
<td>73.8 ± 5.5</td>
<td>72.5 ± 6.8</td>
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<tr>
<td><strong>HRmean (1/min)</strong></td>
<td>181.3 ± 8.0</td>
<td>180.1 ± 7.9</td>
<td>174.7 ± 9.9</td>
<td>174.7 ± 9.9</td>
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<tr>
<td><strong>RPE (B)</strong></td>
<td>19.2 ± 0.8</td>
<td>19.7 ± 0.8</td>
<td>19.3 ± 0.8</td>
<td>19.7 ± 0.5</td>
</tr>
<tr>
<td><strong>RPE (L)</strong></td>
<td>19.3 ± 0.8</td>
<td>19.7 ± 0.5</td>
<td>19.3 ± 0.8</td>
<td>19.3 ± 0.8</td>
</tr>
<tr>
<td><strong>VO2peak (L/min)</strong></td>
<td>4.12 ± 0.83</td>
<td>4.20 ± 0.96</td>
<td>4.14 ± 0.89</td>
<td>4.26 ± 0.78</td>
</tr>
<tr>
<td><strong>VO2mean (L/min)</strong></td>
<td>3.69 ± 0.61</td>
<td>3.86 ± 0.81</td>
<td>3.87 ± 0.86</td>
<td>4.01 ± 0.73</td>
</tr>
<tr>
<td>**VO2peak (ml/kg/min)</td>
<td>56.4 ± 4.7</td>
<td>57.9 ± 6.0</td>
<td>55.7 ± 8.9</td>
<td>58.3 ± 6.4</td>
</tr>
<tr>
<td>**VO2mean (ml/kg/min)</td>
<td>50.7 ± 2.2</td>
<td>53.3 ± 4.7</td>
<td>52.0 ± 8.7</td>
<td>55.0 ± 6.2</td>
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<tr>
<td><strong>RERmax</strong></td>
<td>1.06 ± 0.03</td>
<td>1.07 ± 0.03</td>
<td>1.11 ± 0.04</td>
<td>1.09 ± 0.02</td>
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<tr>
<td><strong>RERmean</strong></td>
<td>1.01 ± 0.02</td>
<td>1.02 ± 0.02</td>
<td>1.01 ± 0.01</td>
<td>1.04 ± 0.01*</td>
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<tr>
<td><strong>VEmax (L/min)</strong></td>
<td>160.2 ± 27.7</td>
<td>156.8 ± 34.6</td>
<td>160.0 ± 39.6</td>
<td>162.0 ± 40.8</td>
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<tr>
<td><strong>VEmean (L/min)</strong></td>
<td>128.6 ± 16.4</td>
<td>129.5 ± 22.3</td>
<td>126.7 ± 26.0</td>
<td>137.1 ± 27.4*</td>
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<td><strong>BFmax (1/min)</strong></td>
<td>61.5 ± 8.2</td>
<td>60.4 ± 9.3</td>
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<td><strong>BFmean (1/min)</strong></td>
<td>46.1 ± 6.4</td>
<td>45.7 ± 5.6</td>
<td>44.3 ± 3.9</td>
<td>45.6 ± 2.8</td>
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<td>**Power outputmean (W)</td>
<td>263.3 ± 48.8</td>
<td>284.9 ± 46.5*</td>
<td>292.9 ± 68.5</td>
<td>306.6 ± 58.1</td>
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<td>**Power outputmean (W/kg)</td>
<td>3.62 ± 0.33</td>
<td>3.96 ± 0.21*</td>
<td>3.93 ± 0.70</td>
<td>4.28 ± 0.54</td>
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<td><strong>Cadencemean (rpm)</strong></td>
<td>99.2 ± 7.4</td>
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<td>99.3 ± 4.0</td>
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<tr>
<td>**Lactate max (mmol/L)</td>
<td>12.62 ± 2.77</td>
<td>13.53 ± 2.44</td>
<td>14.38 ± 2.61</td>
<td>14.29 ± 1.78</td>
</tr>
</tbody>
</table>

4 Discussion

The purpose of this study was to examine the effects on performance and adaptation to training under hyperoxic conditions in comparison to training under normoxic conditions. Furthermore, the training was conducted using a controlled polarized and periodized training scheme.

The main finding from the present study was that only the group training under hyperoxic conditions increased in mean power during the performance test. Both performance and VO2mean were increased for the whole group (HOT + NOT), which shows that it was a good training intervention model.

These findings are similar to those of previous studies (Chich, Stark & Murata 1993; Perry et al. 2005; Perry et al. 2007) in that they showed a significant increase in performance for the whole test group, however they also found a significant improvement for both groups individually, which was not the case in the present study. One reason for this difference could be that our subjects had greater experience of structured cycling training. Less experienced
subjects might have developed a greater increase in performance regardless of the method they used. The increase in power output shows that the training method had a positive effect, however Seiler et.al (2013) showed greater effect while also using 8 min intervals. This difference can probably be explained by an individual response to training, though it is hard to compare studies with different pre- and post-tests. Hämäläinen, Nummela and Ruusko (2000) reported findings similar to the present study, showing a significant improvement in their performance test for those who trained with hyperoxia and no significant improvement for those who trained with normoxia. In both studies, the test subjects were very well used to the training methods utilised and so the margin for improvements could well be smaller.

The results show that the HIIT protocol used in this study gave a significant increase in performance. This can be linked to the principle of specificity (specific training for a specific goal will help achieve it), as the HIIT conducted was specific training for performance on a 20 min all-out test. To verify the specificity, a very strong correlation was found between the mean power output from the performance test and the mean power output from the HIIT sessions. The correlation increased from pre- to post test to near perfect, so a conclusion might be that one can predict a performance outcome on a 20 min all out test based on the HIIT-sessions conducted in this study. This might then be useful for athletes and coaches as a tool in their training.

This type of periodization of the training intervention, with the alternation of HIIT-sessions, is more in line with sports coaching as practiced outside the laboratory. Often training studies have a monotonous setup regarding the choice of intervals, using just one type of work; this is usually because the aim is to evaluate the effect of that type of work alone (Stöggl & Sperlich 2014; Seiler et al. 2013; Perry, et al. 2005; Perry, et al. 2007). However, that approach is unlikely to be adopted in real life training; finding a practical and useful regime should be a primary aim for training intervention research. With the variety of HIIT sessions used in the present study, it could be concluded that the variation made the training mentally easier for the subjects, and this psychological factor is not to be underestimated. The 4 x 4 min-intervals during the easy weeks also gave an alternative stimuli to the longer ones, as the subjects could produce a greater power output, and the periodization within the weeks in this study must be quite unique since it has not been found in any other study that has been investigated.
The HIIT sessions were very controlled, with every second of data logged for power output, cadence and HR. Several other parameters were also taken into consideration during every session, such as lactate and glucose levels, weight, RPE, TRIMP and levels of mood and fatigue. In this way, the subjects could be monitored on almost every aspect in order to reach maximal performance. The intensity of the intervals was controlled by power output and not by HR, because the HR response to this type of strenuous training over time is for it to reduce. The power output was continuously adjusted during the intervals by the supervisors, and this might contribute to the progression of power output throughout the sessions, as the subjects could not see their workload and so were not affected by it. Instead the power output was slightly increased from session to session and in that way, the subjects improved over their normal plateaus. The results show that the model of the training intervention in this study was successful.

This study takes a novel approach to hyperoxic training because of the use of both a periodized and polarized training intervention. In the longitudinal training studies using hyperoxia that has been examined, no findings regarding this has been found. Kilding et al. (2012) stated that their study used a polarized model, but there were no specifics on the model, and no periodization of the training. They used only four weeks of training with two HIIT sessions per week. They did not find any positive results from hypoxic training. So, when using hyperoxia in training, it might be important that the regime is both polarized and periodized in order to acquire the best physiological response. This suggestion is in line with previous research on periodization and polarized training (Kiely 2012; Stöggl & Sperlich 2014).

4.1 Limitations

The subjects starting training level could have been more homogenous (and preferably higher) in VO$_2$max (ml/kg/min) and performance (W/kg). However, other parameters were used primarily for selection for the study, as many of the subjects were also included in another study with muscle biopsies, which the authors had no participation in. Initially, there were nineteen subjects, but only twelve completed the study, which is lower than preferable for statistical purposes. Due to the loss of subjects the matching (mostly performance and VO$_2$max) between the groups was not completely homogenous, but no statistical difference was found. The two subjects who had health related issues is hard to come by. Two subjects were lost to ill health, however the loss of four subjects who were excluded because of
compliance issues could possibly have been prevented by clearer guidelines for inclusion given before the start of the study. However such losses are a reality in human studies where many factors affect the volunteers and their ability to participate throughout a strenuous study.

The timing of the study might also have influenced the selection. The study took place in the spring between March and May. It may have been easier to recruit competitive cyclists in the autumn, when the national competitions and races, which begin in April, are over.

The VO$_2$ data used in this study was taken exclusively from the performance test. A regular VO$_{2\text{max}}$ test was conducted by others involved on all of the subjects both pre- and post the training intervention. However, that data will be reported elsewhere and thus not included in this thesis.

If the whole study had been designed to measure performance after hyperoxic training exclusively, we would have included a threshold related to the VO$_{2\text{max}}$, for example a submaximal test, either a regular incremental lactate threshold test or a constant load test at submaximal intensity. By doing those types of tests, more parameters could have been investigated pre and post, for instance gross efficiency (work economy in cycling) which is linked to exercise performance. However, due to the biopsies and other pre-tests, a threshold test was excluded to avoid overcrowding the test setup.

The O$_2$ concentration cannot be stated full accuracy due to the method used. Since the subjects had individual variation in ventilation, the O$_2$ concentration was between 26-30 %. However, this study was not designed to determine exactly which level of hyperoxia that would give the highest improvement in performance.

4.2 Future research

In future research it would be interesting to take part of empirical knowledge from coaches and athletes to get the training intervention closer to the sport. One way this may be done in cycling is to measure the power output (W) on a regular outdoor training bike. A portable hyperoxic system that could be worn in a small backpack would bring the research closer to the actual sport. To be able to draw more conclusions, the test subjects should be more homogenous in training history and capacity. Some sort of submaximal test should also be
included in the pre- and post-test to give more understanding to the effect given by the training intervention.

A six week training intervention needs reliable test subjects, therefore it is very important to ensure that the subjects know what is expected of them. The higher the training level of subjects included, the closer to reality the training intervention has to be, because it will be more difficult to compromise their regular training.
References


anaerobic capacity and \( \cdot \text{VO}_{2\text{max}} \). *Medicine & Science in Sports & Exercise*, Volume 28(10), pp. 1327-1330

Appendix 1 – Source- and literature search

Aims and research questions:

Which search word did you use?

<table>
<thead>
<tr>
<th>Sökord</th>
<th>Träffar</th>
<th>Rel.</th>
<th>Sökmotor</th>
</tr>
</thead>
<tbody>
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<td>Effects of hypoxia training</td>
<td>110 000</td>
<td>1</td>
<td>Google Schoolar</td>
</tr>
<tr>
<td>Effects of hyperoxic training</td>
<td>25</td>
<td>1</td>
<td>PubMed</td>
</tr>
<tr>
<td>Effects of hyperoxic gas mixtures on exercise</td>
<td>11</td>
<td>1</td>
<td>PubMed</td>
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<td>Hyperoxia training</td>
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<td>88</td>
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<td>PubMed</td>
</tr>
</tbody>
</table>

Where have you searched

PubMed, SportDiscus och Google schoolar.

Searches that gave relevant results?

Comments

Most articles were found by reading other articles
### Appendix 2 – Warm up protocol

**HOT or NOT Project**

<table>
<thead>
<tr>
<th>Tid</th>
<th>Uppvärmning</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>10 minuter</td>
<td>11-12</td>
</tr>
<tr>
<td>10-11</td>
<td>1 minut</td>
<td>14-16</td>
</tr>
<tr>
<td>11-14</td>
<td>3 minuter</td>
<td>11-12</td>
</tr>
<tr>
<td>14-15</td>
<td>1 minut</td>
<td>15-17</td>
</tr>
<tr>
<td>15-20</td>
<td>5 minuter</td>
<td>10-12</td>
</tr>
</tbody>
</table>
Appendix 3 – 24-Hour History

24-Hour History

Name: ________________ Date: __________

How do you feel today? (circle your response)
1) Very, very good
2) Very good
3) Good
4) Average
5) Bad
6) Very bad
7) Very, very bad

How many hours did you sleep last night? _____ How many hours do you normally get? _____

Have you been sick the past week? _____

How would you rate yesterday’s workout? (circle your response).
1) Very, very easy
2) Very easy
3) Easy
4) Average
5) Hard
6) Very hard
7) Very, very hard

How do your muscles feel?
How heavy do your legs feel?
(Fill in each blank with a number)

1) Very, very good ___Arms 1) Not heavy at all
2) Very good ___Legs 2) A little heavy
3) Good ___Overall 3) Heavy
4) Tender, but not sore 4) Very heavy
5) Sore 5) Very, very heavy
6) Very sore
7) Very, very sore

Please respond to the following items as to how you have been feeling the last week including today? Circle the number for each item that best describes you.

<table>
<thead>
<tr>
<th>Feeling</th>
<th>Not at all</th>
<th>A little</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
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<tbody>
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<td>Friendly</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Worried</td>
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<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Miserable</td>
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<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
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<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
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<td>2</td>
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<td>2</td>
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<td>4</td>
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<td>2</td>
<td>3</td>
<td>4</td>
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<td>3</td>
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<td>Rating</td>
<td>Descriptor</td>
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<td></td>
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<tr>
<td>--------</td>
<td>--------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Rest</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>Very, Very Easy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Easy</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Somewhat Hard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very Hard</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
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<td></td>
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</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Maximal</td>
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</tr>
</tbody>
</table>
### Appendix 5 – Example of a HIIT (3 x 8) training session

<table>
<thead>
<tr>
<th>Tid</th>
<th>Uppvärmning</th>
<th>RPE</th>
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</thead>
<tbody>
<tr>
<td>0-10</td>
<td>10 minuter</td>
<td>11-12</td>
</tr>
<tr>
<td>10-11</td>
<td>1 minut</td>
<td>14-16</td>
</tr>
<tr>
<td>11-14</td>
<td>3 minuter</td>
<td>11-12</td>
</tr>
<tr>
<td>14-15</td>
<td>1 minut</td>
<td>15-17</td>
</tr>
<tr>
<td>15-20</td>
<td>5 minuter</td>
<td>10-12</td>
</tr>
<tr>
<td>20-28</td>
<td>Intervall 1</td>
<td>18-20</td>
</tr>
<tr>
<td></td>
<td>8 minuter</td>
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</tr>
<tr>
<td>28-31</td>
<td>Vila 1</td>
<td>10-12</td>
</tr>
<tr>
<td></td>
<td>3 minuter</td>
<td></td>
</tr>
<tr>
<td>31-39</td>
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<tr>
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<tr>
<td>39-42</td>
<td>Vila 2</td>
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<td>42-50</td>
<td>Intervall 3</td>
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</tr>
<tr>
<td>50-60</td>
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<td>10 minuter</td>
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Appendix 6 – Example of a training protocol

<table>
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<th>TID</th>
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<th>RPM</th>
<th>N</th>
<th>WATT</th>
<th>(RPE_{ben} )</th>
<th>(RPE_{and} )</th>
<th>La/GI</th>
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<tr>
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<td></td>
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<td>Gl</td>
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<tr>
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<td>Gl</td>
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<tr>
<td>Nedv</td>
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</tbody>
</table>

Temp (°C) | Kommentar:
---|---
Trimp
Sadel
Styre
Information till försökspersoner

Projektets titel: Betydelsen av syretransport och muskels oxidativa kapacitet för prestation.

PLats för undersökningen: Åstrand Laboratoriet, Gymnastik- och Idrotthsögskolan; Klinisk Fysiologi, Huddinge Hospital

Kortfattad beskrivning av forskningsprojektet:
Under träning som innebär stora muskelgrupper, t.ex. löpning, cykling eller skidförsök, är muskels konstiga för att utnyttja syre (O₂) för att producera energi större än den mängd syre som kan levereras genom cirkulationen. Det är känt att uthållighetsträning ökar blodflödet till muskulturen och att antalet och storleken på muskels mitokondrier (de syreförbrukande organellerna) ökar. Betydande förändringar kan observeras redan efter 4 veckors träning. Inomramning av extra-syre orsakar ökat syre i blodet och arteriell syremätning är förhöjt tillsammans med en ökad arteriell syre koncentration och syreleverans, oberoende av blodflödet. Innanför av extra-syre medger att träna på en relativt högre intensitet och lägre mjölksyrahalt. Ändå måste det visas om kontinuerligt uthållighetsträning med syrgastillsats förbättra prestation mer än uthållighetsträning med vanligt hufvud

Den här studien kommer att undersöka 1) om en högre syrenivå som levereras till 2-ben ger en större ökning av muskels oxidativ kapacitet jämfört mot samma träning med vanlig hufvud och 2) om träning med en högre syrenivå ger större muskular träningseffekt än vid träning med vanlig hufvud. Resultaten kommer att ge ny vetenskaplig kunskap om hur syreupptagnings regleras och hur träningen kan optimaliseras. Studien omfattar en träningsperiod på 6 veckor med labbtest både före och efter träningsperioden.

Hur går studien till?

Test-tillfälle 2 (tidstävande ca 1 timme): Efter ankomsten till laboratoriet kommer du att värma upp för ca 10 minuter och därefter cykla i 40 minuter med den högsta arbetssats du kan arbeta på.

Test-tillfälle 3 (tidstävande ca 45 minuter): Efter ankomsten till laboratoriet (Huddinge sjukhuset) kommer du att ligga på en bräde för mätning med MR-l (magnetic resonance imaging) tekniken. Här mätts muskelsluppen i hela kroppen för att studera förändring av kroppsansammansättning innan och efter träningsintervention.
Appendix 7 – Example of written consent 2(5)


Eftersom fall 1, 2 och 3 kommer du att bedriva utfyllnadstjänstning under 6 veckor. Träningen kommer att sköta på laboratoriet med 3 övervakade högparten pass per vecka på en cykelergometr och två låg intensiva pass genomförda på egen hand. Efter träningssperioden kommer du igen att genomföra samma tester.

En följeomhet på minst 85% kommer att vara obligatoriskt att uppfylla kriterierna för ett fyllnads testerprogram i detta projekt. Detta betyder att du kommer att genomföra minst 13 av 15 hög intensiva pass, 4 av 5 låg intensiva pass under 6 veckor period.

Risken och obelag för deltagande

Före kateterisering, kommer en lokalbehandling ges, så att det blir minsta möjliga obelag. Det är "låg" risk och minimalk obelag för försökspersonal med injektion av kall salthämtning för mätning av blodflöde. I sällsynta fall kan en bloduppg bildas eller det kan finnas mindre blödning från att ha en kateter på plats under längre perioder, men erfarna läkare har stor kunskap och erfarenhet av att på ett säkert sätt ta hand om dessa ovanliga situationer.

Muskelbiopsi, Muskelsbiopsi innebär att en länk bit muskelvävnad (ca 0,10 gram) tas ut med en speciell. Muskelsbiopsi utförs efter lokalbehandling av huden och underliggande bindväv. Ett 4-5 mm långt snitt görs genom huden, genom vilket biopsinälen föras in och ett muskelprov tas ut. Själva ingreppet med biopsinälen är över på ett par sekunder. I allmänhet känns en muskelbiopsi
som ett trubbigt slag mot benet. I vissa fall kan en skarspare smärta känna sig, som går över så fort nålen tas ut. För att förhindra blodutgjutning i muskeln lägger vi ett lokalt tryckförband över biopsistället, som skall vara kvar under 1-2 timmar. Liksom vid alla hudsnitt kan en hudnerv skivas av med lokalt känselförtfall i huden som följd. Vid den här typen av biopsi är denna komplikation mycket ovanlig. I de fåtal fall där denna komplikation har ägt rum har allt normaliserats efter 6-12 månader.

**Skötselinstruktioner vid muskelbiopsi:** Under veckan före muskelprovtagning får du ej använda magnezyl eller någon annan medicin som innehåller acetylsalicylsyra (alvedon går bra). Två dygn (48 timmar) före testerna får du ej utföra något tungt fysiskt arbete (~30 min) eller använda alkohol. Under veckan efter undersökningsen skall du inte bada (p.g.a. infektionsrisk) och när du duschar skall du skydda området över biopsistället med plast. De inre vita långsmala påstren skall du inte byta själv – de ramlar av efter ca 1 vecka.


**Frihet att dra sig ur studien och ersättning**

.......................................................... ..........................................................
datum namnteckning och namnfasttydligande

..........................................................
föröksledare

Deana blankett finns i två liklåda kopior varav é och föröksledare har var sin kopia
Appendix 7 – Example of written consent 4(5)

Studieansvarig: Robert Bonsel e-postadress: robert.bonsel@gih.se, mobilnummer: 0704763412
Doktorandstudent: Daniele Cardinale daniele.cardinale@gih.se, mobilnummer: 0737014415
Lärare: Eva Andersson: eva.andersson@gih.se, mobilnummer: 0739460354
Informerat samtycke (biobank)

Undertecknad har tagit del av den skriftliga informationen.

Jag accepterar

**att delta i forskningsstudien rörande** ”Betydelsen av syretransport och muskels oxidativa kapacitet för prestation.” och har förstått att mitt deltagande är helt frivilligt och kan avbrytas när som helst utan någon förklaring.

Jag godkänner

**att de vårnadsprov som jag lämnar kommer att förvaras i biobank vid GIH (Gymnastik- och Idrottsförskningsinstitutet),**

**att proverna används på det sätt som beskrivits i forskningspersoneninformationen men att jag när som helst kan återkalla mitt samtycke till användning av mina prover och begära att proverna ommedeltart förstörts eller avidentifieras,**

**att proverna används i framtida biomedicinsk forskning som inte är beskriven här och som i förekommande fall kommer att granskas och godkänas av regional etikprövningsnämnd samt att i samband med sådan forskning journalkopier eller information baserad på min journal lämnas ut (stryka om forskningspersonen motsätter sig det).**

Datum:........................................

Underskrift:..........................................................

Namnförrydlingande:...........................................

Personnummer □ □ □ □ □ □ □ □ □ □ □

Dokumentet är upprättat i två original varav forskningspersonen behåller den ena och det andra arkiveras av ansvarig prövare.
Appendix 8 – Pictures from study 1(5)
Appendix 8 – Pictures from study 2(5)
Appendix 8 – Pictures from study 3(5)

![Image of a laptop and data sheet]

The image shows a laptop with a data sheet attached to it. The data sheet contains various columns and rows with data entries. The columns include TID, PULS, RPM, HP, WATT, IN, MAX, Leb, and brick. There are also rows labeled Int 1, Int 2, Int 3, and Int 4. The data includes numerical values for each column.

The sheet also includes sections for comments, with entries for Temp (°C), Thresh, Sadel, and Styre.
Appendix 8 – Pictures from study 4(5)
Appendix 8 – Pictures from study 5(5)