Mastergradsoppgave

[The effect of two different types of resistance training on the cycling performance of highly trained veteran cyclists]

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MKØ210

Mastergradsoppgave i

Kroppsøving

SAMTYKKE TIL HØGSKOLENS BRUK AV MASTEROPPGAVE I KROPPSØVING

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underskrift

“The effect of two different types of resistance training on the cycling performance of highly trained veteran cyclists”

Abstract

The aim of this study was to investigate the effect of high resistance/low repetition vs low resistance/high repetition strength training on cycling performance. Twenty-three highly trained male veteran cyclists were randomly allocated to three different groups before starting a nine-week resistance training intervention. The first group (*n* = 9) high resistance/low repetition (4 RM), the second group had low resistance/high repetition (20 RM, *n* = 7) and the last group was the control group (*n* = 7) that had no resistance training. The resistance training intervention consisted of whole-body exercises in different apparatuses with two sessions per week in addition to normal endurance training. The strength tests consisted of leg press and chest press at both 1 RM and 80% sub-max (number of repetitions). To measure the interventions´ effect on the cycling performance two tests were performed on a Velotron ergometer-cycle. The first test was a lactate profile and VO_{2max} test and secondly there was a twenty-minute all-out time-trial. There were found significant improvement in both resistance training groups on the strength tests ($p < 0.05$), while no significant changes were found in the control group. All groups had a significant greater increase in Watt at LT, and production of watts on the twenty-minute all-out time-trial. The intervention groups had significant a improvement in maximum aerobic power on the VO_{2max}-test. No significant changes were found in any group concerning VO_2, blood lactate values, cadence or weight. According to these findings, adding resistance training to usual endurance training improves cycling performance in trained cyclists.

Key Words: cycling, strength training, endurance, work economy, lactate, VO_2

Sammendrag

For å undersøke hvilken effekt to forskjellige typer styrketreningsregimer hadde på prestasjonen i sykling, ble 23 godt trente mannlige veteransyklister tilfeldig fordelt på tre grupper; en gruppe hadde tung styrketrening med få repetisjoner (4 RM, n = 9), en annen gruppe hadde lettere styrketrening med mange repetisjoner (20 RM, n = 7), mens den siste gruppen var en kontrollgruppe (n = 7) som ikke hadde styrketrening. Styrketreningsintervensjonen bestod av to økter i uken over en periode på 9 uker. Styrketreningsprogrammet forsøkspersonene fikk bestod av øvelser i forskjellige styrketreningsapparater for hele kroppen. Alle gruppene hadde utholdenhetstrening som vanlig utenom. Testene ble gjennomført i fysiologisk testlaboratorium ved Høgskolen i Bergen. Styrketestene var 1 RM og 80 % submaks (antall repetisjoner) i beinpress (høyre og venstre fot hver for seg) og brystpress. Sykkeltestene bestod av en laktatprofil og VO_{2maks} – test og en 20 minutters prestasjonstest. Studiet konkluderer med at begge styrkegruppene hadde en signifikant ($p < 0,05$) økning i styrkeøvelsene, samt signifikant større økning enn kontrollgruppen i MAP (maximum aerobic power) på VO_{2max}-testen. Alle gruppene hadde signifikant økning i produksjon av terskelwatt og watt produsert på prestasjonstesten. Ingen signifikant endring ble funnet blant gruppene på noen av testene vedrørende VO_2, laktatverdier, vekt, rpm eller HF. Basert på disse funnene, at begge typene styrketrening gir gode resultater på styrketester og i sykkelprestasjon, anbefales syklister å trene styrketrening sammen med vanlig utholdenhetstrening.

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1.0 Introduction

The obvious way to improve cycling performance is to train (Rønnestad et al, 2011). But on which type of training to focus on the most would be more difficult to answer. A common belief has been that resistance training declines a person´s ability to perform in endurance sports such as cycling. In what way resistance training may improve cycling performance is yet inconclusive, but there are several possible theories. Several studies have reported an improvement in performance in endurance sports after a maximal resistance training intervention (Raastad et al. 2009, Jackson et al. 2007, Østeraas et al. 2002, Støren et al. 2008).

There is also some documentation of heavy resistance training improving both running economy and cycling economy (Raastad et al. 2009, Sunde et al. 2010). One theory is that the cycling economy is improved due to resistance training, which leads to a decline in energy cost and therefore a better performance. The improvement in work economy results in a higher cadence or more power in each pedal thrust. Another suggested theory is that high repetition/low resistance training may benefit endurance sports by increasing lactate threshold, an important factor in performing in endurance sports. A third theory is leg muscle recruitment (neuromuscular adaptations) benefits performance in endurance sports (Bonacci et al. 2009). While there is some evidence of maximal resistance training improving endurance performance, there are is evidence of to which point high-repetition resistance training influence the same performance. The effect of different types of resistance training on cycling performance is unclear.

To date, no comparison of two different types of resistance training has been carried out using highly trained veteran cyclists. A previous study has used club-level trained cyclists to investigate differences between high resistance/low repetition and low resistance/high repetition on the cycling performance (Jackson et al. 2007), but these two studies differ in both the testing protocols as well as the subjects used.

The purpose of this study was to investigate which type of resistance training added to usual endurance training, 4 RM or 20 RM, affected cycling performance on a twenty-minute all-out time-trial the most. Secondly, it was investigated to which point a lactate profile and VO_{2max}

test was affected by the same types of resistance training. The subjects are twenty-three trained veteran cyclists.

2.0 Methods

2.1 Experimental approach to the problem

In order to investigate to which point an 8-week pre-to-post training intervention evaluated the effect of heavy resistance leg-strength training on cycling performance. Twenty-three subjects were randomly allocated to either a maximal resistance training group (MRT, $n = 9$), a sub-maximal resistance-training group (ERT, $n = 7$) and a control group (CG, $n = 7$). Twenty-six trained veteran cyclists originally participated in the study, but mid study, three subjects had to withdraw their involvement because of injury and illness. This was the reason for the uneven numbers in the groups. The MRT trained with 3x4 repetitions two days per week, the ERT trained with 3x20 repetitions two days per week, while the CG continued their standardized training program. The subjects were made familiar with resistance training and testing procedures over a period of two weeks before entering the intervention-training period. Training was performed during the winter preparation period from January to March. The subjects were tested for 1 RM and 80% sub-max (number of repetitions) in leg press and chest press. Cycling performance was measured by conducting a twenty-min all-out time-trial as well as a lactate profile and VO_{2max} test during cycling on a Velotron ergometer pre and post the training intervention.

2.2 Subjects

Twenty-three male veteran cyclists aged between 35 and 59 volunteered to participate in the study. All subjects had been cycling actively for at least the past seven years, and regularly exercised 10 – 15 hours per week. Some of the subjects occasionally competed in other endurance sports such as triathlon, marathon or long distance cross-country skiing, but all had cycling as their main sport. There were set requirements that the cyclists had to meet in order to be allowed to participate in the study. The first requirement was that the time used to complete last year´s local one-day race form Bergen to Voss (162 km) did not exceed 5 hours (record 3h 42 min). The second requirement was that the cyclists could document a month of training directly prior to start of the study. The subjects´ recent training status, physiological characteristics and anthropometrics are shown in table 1. The study was approved by the Norwegian Social Science Data Services. All subjects were fully aware of the nature of the study and received information in both writing and an oral presentation, as well as information about the experimental risks, before signing written informed consent to participate. It was made explicit that subjects could withdraw from the study without giving any reason for doing so. From pre- to post-test two subjects withdrew from the study due to injury and one additional due to a lack of training.

Table 1.
Baseline characteristics of the twenty-three male veteran cyclists participating in the study (mean and range)

	Baseline (n = 23)
Age (yrs)	45.1 (35 – 59)
Body mass (kg)	79.2 (64.9 – 90.8)
Body height (cm)	181.5 (173 – 192)
VO_{2max} mL x kg^{-1} x min^{-1}	57.3 (48.8 – 69.4)
HR_{max}	175 (155 – 196)
Training last month (pre study start, hrs)	48 (38 – 70)

The subjects were divided into three groups; the first group was high resistance/low repetition (4 RM, *n* = 9). The second group was low resistance/high repetition (20 RM, *n* = 7), and the third group was the control group (*n* = 7). The control group had endurance training as normal, and the two other groups had resistance training twice a week in addition to the endurance training. The allocation of the training groups was conducted at HIB (Bergen University College). All the names were first divided into three groups according to age. This was carried out so that there was an even spread of ages within each group.

2.3 Testing procedures

The pre-tests were all conducted over a period of two and a half weeks. In the first week of pre-testing the control group was tested, and during the following ten days the two other groups were tested. Each subject was tested in 1 RM and 80 % sub – max on both leg press and chest press apparatus (picture 1). The test-apparatuses were produced by Cybex (Cybex International UK Ltd.). Each subject was also tested for maximal oxygen uptake (VO_{2max}), oxygen uptake and production of watts at the lactate threshold (VO_{2LT} and VO_{2watt}) and a twenty- minute – all – out performance test. These tests were all conducted on a Velotron cycling ergometer pre and post the training intervention.

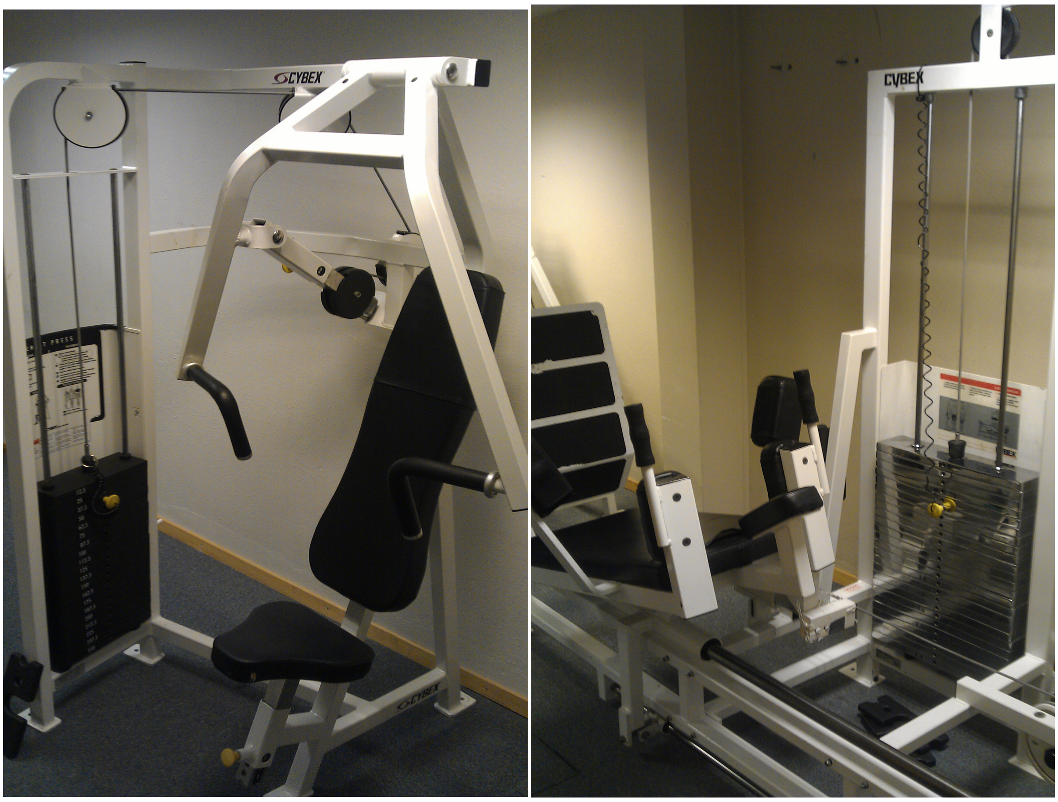

Figure 1:

The figure shows the strength training apparatuses used to test 1 RM and 80% sub-max. Left: the chest pre apparatus. Right: the leg press apparatus.

There were three different test days, with one day of rest after each day. On the first test day subjects performed either the strength test or lactate threshold test with VO_{2max}. The subjects that performed the strength test on the first test day performed the VO_{2max} test on the second test day and vice versa. The same order of testing used in the pre-tests was repeated for each subject during the post-tests. The subjects were also told not to have heavy resistance training or endurance training with greater intensity than zone 3 on the day before a test. They also had to take both the pre- and post-test at approximately the same time of the day. All of the subjects took the performance test on the last day of testing.

Before the strength test the subjects had a ten-minute warm up on either a cycle ergometer or a treadmill, and then they proceeded with additional warm up exercises using the same apparatus that was used then in testing. The warm up on both the leg-press and chest-press apparatus consisted of first 10 reps, then 5 reps and finally 2 reps, before the subjects were tested in 1 RM. A stopwatch was used to ensure that the subjects received a three-minute break between warm up sets. First the subjects were tested in 1 RM on the leg press apparatus. After the 1 RM test on both right and left foot the subjects had the 1 RM test on the chest-press apparatus. Thereafter the subjects were tested on 80% sub-max on the leg-press as well as the chest-press. On the sub-max test the subjects had to complete as many repetitions as they could. A metronome set to 90 bpm (1/4 stroke) was used on the sub-max test so that the subjects knew when to start each contraction. If they were too late in starting the contraction would not be approved. A MuscleLab (Ergotest, Porsgrunn, Norway) was attached to the weights that were lifted by the subjects. This way the exact number of contractions and the correct speed on each contraction was measured.

Two tests were conducted on a Velotron cycle ergometer (Velotron Dynafit Pro with velotron coaching racermate software, Racermate Inc. Seattle, USA) located in the physiologic test lab at HIB. The instrument that was used to measure O_2 was the Oxycon Pro O_2 (Oxycon Pro Metabolic Cart, CareFusion Germany). The first test on the Velotron cycle ergometer was a lactate profile test with VO_{2max}. Each subject was weighed before the start of the test. The subjects started with a warm up at 100 watts for ten minutes. After ten minutes, lactate and O_2 was measured and the resistance was increased to 150 watts. From this point the resistance was increased by 30 watts every four minutes, and values for RPM, O_2, lactate, VE (l/min), RER and HR were written down. Each subject had the opportunity to choose their own cadence / rpm. The test was over when the subject exceeded 3mmol/L lactate value (Lactate Scout, Sports Resource Group Inc, USA). No protocols for rpm were set. Each subject had the opportunity to choose the rpm that they wished. After the subject exceeded a value of 3mmol/L the lactate profile test was over.

Then the subjects were told to cycle at 100 watts for three minutes before the VO_2max-test started. This was an all-out test where the subjects started at the resistance level they had reached in the lactate profile test prior to when the lactate value exceeded 3mmol/L. The resistance was increased with thirty watts every thirty seconds until the subject was fatigued. During this part of the test the researchers asked the subject whether he was physically able to continue cycling at the resistance level he had reached and he was told to respond with a “thumb up” or “thumb down” gesture. If the subject responded with a “thumb up”, the resistance was increased. If the subject showed a “thumb down”, the resistance was not increased. The resistance each individual subject reached when fatigued, were used as a measure of maximum aerobic power (MAP). The subjects were also allowed to stand up at any point of the VO_{2max} test. At this part of the test the researchers motivated and cheered for the subject. The reason for that was that the Oxycon Pro was set to measure every thirty seconds, so it was important that the subject reached the end of a thirty second interval in order for their performance to be measured. Once the VO_{2max} test was completed, the mean of the last two measurements was defined as the subjects VO_{2max}.

The other test on the Velotron cycle ergometer was a twenty-minute performance test. The main goal of this test was to produce as much wattage as possible. When the subjects arrived at testing height and weight were measured. The subjects started with a ten-minute warm up during which they had to stay between 100 and 150 watts. After ten minutes they had an additional five-minute warm up but they were allowed to change gear if they wanted. Their performance during the additional five minutes was taken into account from pre-test to post-test. If a subject stayed closer to 150 watts during warm up at pre-testing he was told to do the same during post-testing. During the tests the subjects were not allowed to know any information other than which gear they were using and the time on the stopwatch. After warm up (10 + 5 minutes) the twenty-minute test started. During this test the subjects shifted gears as they wanted, but the starting gear chosen for the pre-test was used again for the post-test. The subjects could also choose heir own rpm. Lactate was measured after ten and after twenty minutes of the test, and O_2 values were measured four times during the test. This was between minute four and five, minute nine and ten, minute fourteen and fifteen and then during the final minute of the test. As in the VO_{2max} test the mean of the last two values at each stage was defined as the subjects VO_2 at the specific stage. Currell et al. 2008 listed 7 factors about performance tests that need to be followed in order for the test to be valid. These were all taken in consideration and followed.

2.4 Training procedures

The subjects were given a detailed resistance training program for the ten week intervention. The program had exercises for the whole body and had to be completed twice a week. On days were the subjects had two training sessions the subjects were asked to prioritize the resistance training. The resistance training program is given in Figure 2. The subjects filled out the programme as they completed training sessions of both resistance and endurance. All subjects got the programme by hand as a training diary to bring along to training sessions and on email so it would be easy to fill out and return.

Figure 2.

Resistance training program during the intervention.

STYRKE									
	Dag 1					Dag 2			
Øvelser									
Leggpress H									
Leggpress V									
Tåhev									
Hoftebøy									
Brystpress									
Nedtrekk									
Skulderpress									
Mage									
Rygg									
UTHOLDENHET									
	50-72 %	73-82%	83-87%	88-92%	93-97 %	97-	Akktivitet		
Mandag									
Tirsdag									
Onsdag									
Torsdag									
Fredag									
Lørda									
Søndag									
Notater:									

The subjects had different knowledge of resistance training and testing before the start of the study. Therefore, all subjects were given a 10 – 12 RM adaptation to resistance training the first two weeks of the program. After the two-week adaptation program subjects in the 20 RM group were told to start the 20 RM program. The 4 RM group could choose to have one week with 6 – 8 RM before they started on the 4 RM program. An important notice is that the control group were given the same two-week adaption to resistance training with 10 – 12 RM. This was done for two reasons. The first reason was to decrease the possibility for injuries when the control group was tested. And the second reason was to create a stronger baseline within the subjects where all subjects where familiar with the apparatus used in testing.

The training programme had eight different exercises. The exercises were leg press, chest press, shoulder press, toe lift, sit ups or other abdominal exercises of the individual subjects choice, upper back and lower back flexion and hip flexion. On the abdominal exercises and lower back flexion exercises, the subjects could choose exercises as they wanted and were told to have 10 – 15 RM throughout the intervention period. On all the other exercises the subjects were told to have resistance that fit the group they were assigned to. A few days before intervention start the subjects were invited to have a review of all the exercises. All the exercises were conducted on apparatus and not with free weights. This was done because of lower demand for technique and to decrease the possibility for injuries.

2.5 Short survey

After post testing all subjects were asked to participate in a short survey about the study and how they were affected by the training during the study. The survey was not validated and was used exclusively to get an impression about the subjects´ experiences with resistance training. The questions were about fatigue before and after the intervention, work load throughout the study, number of training sessions and if they feel any difference in the riding experience. The questions were formed in a way so that all subjects could participate regardless which group they were in. The survey was through e-mail and not in person.

2.6 Statistics

After each performed test, the results were plotted in different forms made in Excel, version 2010 (Microsoft Office 2010). There were made a form for each subject on each of the five tests. On these forms the researchers plotted min and max values on variables that were set in advance. Then the mean values were calculated on the different variables for each of the three groups. Once all the statistics had been plotted the different analyses could be made. There were also made a statistics form were the values on the different variables from the lactate profile test were plotted. This was done to calculate each subjects´ different lactate threshold values. A diagram was made to find the different subjects 3mmol/L values. On this form mean, standard deviation and paired samples t-tests were used to calculate differences in one group from pre-test to post-test. Independent samples t-tests were used to find differences between the groups. Change in percent was also calculated as well as the actual value. All analyzes resulting in $p \leq 0.05$ were considered significant.

3.0 Results

There were no significant differences between the training groups in any of the strength tests or cycling tests before the intervention period started.

3.1 Strength tests

Both of the training groups had gains in strength on the 1 RM-tests. Table 2 shows the changes from pre-test to post-test in percent. Note that all of the changes in the 20 RM group were significant (leg press L, $p = 0.004$, leg press R, $p = 0.009$, chest press, $p = 0.010$), while only some of the results were significant for the 4 RM group (leg press R, $p = 0.012$, chest press, $p = 0.019$). Also note that none of the results in the control group were significant. There were no significant differences when comparing the two intervention groups.

Table 2. Pre- and post-test scores, as well as difference from pre to post in percent, on leg press and chest press performance in 23 highly trained veteran cyclists (mean and SD).

	4 RM (n = 9)	**20 RM (n = 7)**	**Control group (n=7)**
Leg press 1RM,L pre	88.89 ± 10.24	88.75 ± 8.91	100.42 ± 6.60
Leg press 1RM,L post	92.50 ± 11.11	98.75 ± 13.01	99.17 ± 9.04
Difference	**4.1%**	**11.3% ***	**-1.2%**
Leg press 1RM,R pre	90.83 ± 12.44	92.00 ± 10.81	101.25 ± 5.18
Leg press 1RM,R post	96.39 ± 12.75	101.50 ± 14.21	101.67 ± 8.01
Difference	**6.1% ***	**10.3% ***	**0.4%**
Chest press 1RM, pre	57.78 ± 7.23	61.67 ± 10.68	60.71 ± 13.59
Chest press 1RM, post	63.33 ± 7.81	67.08 ± 8.58	63.93 ± 13.61
Difference	**9.6% ***	**8.8% ***	**5.3%**

L = left foot, R = right foot. * Changes are significant ($p < 0.05$).

Table 4 shows number of repetitions completed on the 80% sub-max tests. Note that all results in the 20 RM group were significant, while only leg press on right foot was significant for the 4 RM group ($p = 0.015$). None of the results were significant for the control group.

When compared against each other, the 20 RM group scored significantly higher than the 4 RM group on the leg press 80% test, both left and right foot (p = 0,017 and p = 0,010).

Table 3. Pre- and post-test scores, as well as difference from pre to post test in percent, on leg and chest press 80% sub-max test, number of repetitions (Mean ± SD).

	4 RM	**20 RM**	**Control group**
Leg press, L, pre	12.00 ± 3.46	19.33 ± 14.51	9.00 ± 2.61
Leg press, L, post	13.78 ± 7.03	31.00 ± 17.09	11.50 ± 5.21
Difference	**12.7%**	**60.3% ***	**27.8%**
Leg press, R, pre	11.11 ± 2.62	16.40 ± 8.82	8.33 ± 2.25
Leg press, R, post	15.44 ± 6.56	31.20 ± 12.93	9.33 ± 4.41
Difference	**39.0% ***	**90.2% ***	**12.0%**
Chest press, pre	8.67 ± 2.55	8.00 ± 2.45	7.14 ± 1.22
Chest press, post	10.56 ± 2.46	11.17 ± 2.56	8.71 ± 3.90
Difference	**21.8%**	**39.6% ***	**22.0%**

L = left foot, R = right foot. * Changes are significant ($p < 0.05$).

3.2 VO_{2max}-test and calculated lactate threshold values

There were not found any significant change in VO_{2max}. On the same test both intervention groups had significant improvement in MAP (4 RM p = 0.035, 20 RM p = 0.030, Table 4) , while results were not significant for the control group.

Table 4. Pre- and post-test scores as well as difference from pre- to post-test in VO_{2max} and MAP, on VO_{2max}-test (Mean ± SD).

	4 RM	20 RM	Control group
VO_{2max} (mL x kg^{-1} x min^{-1})	58.41 ± 8.04	56.10 ± 3.05	57.16 ± 7.21
VO_{2max} (mL x kg^{-1} x min^{-1})	59.32 ± 8.56	56.37 ± 3.82	58.56 ± 6.03
Difference	**1.5%**	**0.4%**	**2.4%**
MAP (W), pre	423.33 ± 40.00	390.00 ± 38.73	428.57 ± 56.69
MAP (W), post	436.67 ± 35.00	407.14 ± 38.17	462.86 ± 45.36
Difference	**3,1%***	**4,4%***	**8,0%**

MAP = maximum aerobic power, the individual subjects´ specific resistance in watts when fatigued at the end of VO_{2max} test. * Changes are significant ($p < 0.05$).

All the groups showed a significant increase in threshold wattage (W_{LT}) from pre-test to post-test. The 4 RM group had an increase of 10,5% (p = 0.009), the 20 RM group had an increase of 10.1% (p = 0.011) and the control group had an increase of 8.7% (p = 0.026). The 4 RM group had a significant increase in HR_{LT} (p = 0.009, Table 5), which is HR at lactate threshold.

Table 5. Pre- and post-test scores as well as differences in percent, on Wattage, Wattage pr kilogram, Heart rate and VO_2, 3mmol/L lactate threshold values (Mean ± SD).

	4 RM	20 RM	Control group
$Watt_{LT}$, pre	243.22 ± 44.7	247.43 ± 41.72	266.71 ± 37.71
$Watt_{LT}$, post	268.67 ± 50.4	272.43 ± 48.21	290.00 ± 48.07
Difference	**10.5%***	**10.1%***	**8.7%***
$Watt/kg_{LT}$, pre	3.14 ± 0.62	3.27 ± 0.43	3.16 ± 0.45
$Watt/kg_{LT}$, post	3.50 ± 0.70	3.60 ± 0.45	3.45 ± 0.52
Difference	**11.3%***	**10.0%***	**9.4%***
HR_{LT}, pre	149.67 ± 12.51	159.29 ± 10.83	149.86 ± 8.49
HR_{LT}, post	155.33 ± 11.27	159.14 ± 10.90	151.00 ± 5.86
Difference	**3.8%***	**-0.1%**	**0.8%**

VO_{2LT}, pre (mL x kg^{-1} x min^{-1})	45.69 ± 6.65	46.16 ± 5.20	43.12 ± 16.60
VO_{2LT}, post (mL x kg^{-1} x min^{-1})	47.69 ± 8.00	46.67 ± 5.57	47.14 ± 4.31
Difference	**4.4%**	**1.1%**	**9.3%**

* Changes are significant (p < 0.05).

3.3 Twenty-minute all-out performance test

On average watt produced on the performance test all the groups had a significant gain from pre to post test. The 4 RM group had the most increase with 5,5% (p = 0.031). The 20 RM group had a 5,1% (p = 0.002) increase and the control group had an increase of 4,7% (p = 0.026).

Table 6. Pre- and post-test scores as well as differences from pre- to post-test in percent, in avg. watts and avg. watts/kg, on the twenty-minute performance test (Mean ± SD).

	4 RM	20 RM	Control group
Avg. Watts	287.18 ± 35.49	269.24 ± 43.82	307.97 ± 29.46
Avg. Watts	303.11 ± 38.98	283.03 ± 46.52	322.54 ± 31.74
Difference	**5,5%***	**5,1%***	**4,7%***
Avg. Watts/kg, pre	3.72 ± 0.60	3.47 ± 0.42	3.64 ± 0.36
Avg. Watts/kg, post	3.97 ± 0.71	3.73 ± 0.40	3.85 ± 0.37
Difference	**6,6%***	**7,6%***	**5,6%***

* Changes are significant (p < 0,05).

3.4 Survey

The subjects also answered a short survey about training during the study and its different affections. The survey was six questions formed in a way that the subjects would find them easy to read and could answer fast. Although not validated, the survey was still proceeded with to find out the subjects thoughts about the combination with resistance training and endurance training. They were also asked if their involvement in the study left them more fatigued in everyday life and/or other training compared to before study start, as well as if they felt any improvement in the riding experience.

Table 7. Questions and results from the survey in percent.

Questions			
1. Have you used resistance training together with endurance training before study start?	Yes, at a regularly basis: 20%	Never used before: 30%	Yes, but not at a regularly basis: 50%
2. In everyday life in general (work, spare time, weekend), are you more fatigued now than before study start?	Yes, more fatigued: 0%	No, less fatigued: 20%	Don't know, not noticeable: 80%
3. Compared with other training and cycling performance, are you more fatigued now than before study start?	Yes, more fatigued: 0%	No, less fatigued: 20%	Don't know/not noticeable: 80%
4. Has the riding performance changed during the study?	Yes, better performance: 60%	No, worse performance: 0%	Don't know/not noticeable: 40%
5. During the study, was the total amount of training hours per week to high?	Yes, too high: 0%	Sustainable amount: 80%	No, could be more: 20%
6. Will you use resistance training regularly in your weekly training in the future?	Yes: 100%	No: 0%	Don't know: 0%

20 subjects answered the survey. (4 RM n = 8, 20 RM n = 7, CG n = 5).

4.0 Discussion

The aim of this study was to investigate in what way two types of resistance training added to usual endurance training affected cycling performance. Twenty-three highly trained veteran cyclists were randomly allocated to either a heavy (4 RM) resistance training group, a high-rep (20 RM) resistance training group or a control group. The training groups had an 8-week resistance training intervention. Cycling performance were measured pre and post the training intervention with a lactate profile and VO_{2max}-test and a twenty-minute all-out time-trial. Two major findings in the study were that 1) all groups had a significant increase, from pre- to post-test, in watt per kilogram on the twenty-minute all-out time-trial and a higher increase in watt per kilogram at lactate threshold levels. 2) The intervention groups had a significant increase in MAP on the VO_{2max}-test from pre- to post-test while the control group had no significant increase.

The significant higher increase in MAP in the intervention groups leads to either cycling at higher intensities over a greater distance, or a to produce greater deal of power on the same intensity. Either way it benefits the two intervention groups in performing in cycling.

4.1 Strength tests

Both intervention groups improved 1 RM on chest press significantly. Since the subjects are trained male veteran cyclists, one would think that there is potentially a bigger chance of gaining strength in untrained upper body muscles than in trained leg muscles. The biggest difference on the chest press test was found in the 4 RM-group that had a 9.6% gain. This gain equals 5.56 in kilograms. The 20 RM-group had an 8.8% gain on the same test (5.42 kg). The control group did not have a significant gain in 1 RM on this test.

The findings on the 1 RM leg press-test did not come out as expected. On both feet the 20 RM group had a significant greater gain than the 4 RM group. This is not in agreement with principles of training that states that heavy resistance training improves maximal strength the most. It is also not in agreement with 1 RM tests in a similar study (Jackson et al. 2007). One reason for the outcome on the 1 RM tests could be differences between the apparatuses used by the subjects in training and the apparatus used in testing. As shown in picture 1, the leg press apparatus used in testing had almost a lying-down position (approximately 75-80º, lying down completely would be 90º), while other common leg press apparatuses has a more sitting-up position. Training in one type of apparatus and testing in a different would not be considered appropriate. Another reason for the outcome could be the subjects´ different knowledge of and experiences with resistance training. This could result in different adaptation to the resistance training. A third cause could be that some of the subjects did not perform optimal on the specific test day. This factor would of course be of great importance on all tests. When testing on a small group (n=9) one or two bad tests would hold back the groups average. Of the nine subjects in the 4 RM-group two failed to gain in leg-press.

Another interesting point is that improvement found on the 1 RM tests in the present study were lower than what was found in other similar studies (Sunde et al. 2010 and Jackson et al. 2007). A suggestion for this outcome is that the training intervention in those studies

consisted of exercises with free weights. The use of free weights has been found to improve resistance training more, compared to the use of exercise apparatuses.
The author suggests that since there were found no significant change in weight in any of the groups, the improvement in strength is mainly caused by neural adaptations (Sunde et al. 2010). The body composition was not measured in this study, but since the subjects were highly trained lean veteran cyclists, the significant increase on the strength tests are most likely due to neural adaptations instead of hypertrophic adaptations that probably have lead to an increase in bodyweight.

As expected the 20 RM group had the most increase in number of repetitions on all 80% sub-max tests. As shown in table 4 all results in the 20 RM group where significant. This is more in agreement with existing training principles about high repetition/low resistance vs. low repetition/high resistance.

4.2 VO_{2max}-test and calculated lactate threshold values

Lactate levels are effective in determining potential cycling performance. It is widely accepted that lactate is used as a criterion measure for aerobic endurance performance. Faude et al. 2009 lists different studies where they used so-called fixed blood lactate thresholds. In these studies lactate levels were set to 2, 2.5, 3 and 4 mmol/L. In this study the lactate threshold was set to 3,0 mmol/L. An interesting finding was that both resistance-training groups significantly produced more watts at lactate threshold on post-tests than pre-tests. The control group also significantly increased $watt_{LT}$ production but, in percent, not as much as the two resistance-training groups. These findings were expected, for the reason that the subjects had over two months of training and were getting closer to season start. Study start was in January and post-test was in March/April.

While the production of watt at lactate threshold ($watt_{LT}$) and level of MAP (maximal aerobic power, resistance at end of VO_{2max}-test) was significantly increased in both intervention groups, the $\%VO_{2max}$ and $\%HR_{max}$ at lactate threshold showed no significant change. In order to understand these findings Bassett and Howley 2000, listed important factors behind performance in endurance sports to be VO_{2max}, $\%VO_{2max}$ at LT and work economy to affect the velocity at LT and maximum performance velocity. Since the tests in this study were indoors, the importance of equipment is lowered and external factors were equal to all subjects during testing. The subjects in this study did not improve significantly in VO_{2max} or

%VO_{2max} at LT. The last factor to affect velocity at LT is work economy. This is in agreement with several studies that showed that maximal resistance training improves work economy in cycling, running and cross-country skiing (Sunde et al. 2010, Støren et al. 2008, Østeraas et al. 2002).

The 4 RM group had according to Table 5 a significant increase in HR_{LT}. Looking at the datasets seven of the groups´ nine members had an increase in HR. Along with the two other groups the 4 RM group did not have a significant increase in %HR_{max} at the same test.

4.3 Performance test

While there were, as mentioned, found a significant increase in watts produced on the performance test in all groups, no significant findings where found in VO_{2max}, cadence, blood lactate values or weight. Cycling economy is related to a decrease in %VO_{2max} to sustain a given mechanical work (Faria et al. 2005). All groups had a significant increase in watts and no significant increase in %VO_{2max}. Another possible reason could be increase in technique. Data for technique will not be commented.

4.4 Survey

The most interesting finding in the non-validated survey was that all subjects in the study want to use resistance training at a weekly basis in the future. This probably have to do with the fact that the subjects have spoken together, or some of the subjects have spoken with the researchers about they think would better the performance. 60% of the responders on the survey think that the riding performance has improved, while 40% feels no difference in riding performance during the study. None of the subjects answering the survey feels a decrease in riding experience. Also, none of the subjects found the amount of training hours per week during the study too high. This is not in agreement with Jackson et al. 2007, which stated that neither of the resistance-training groups could persist with the same amount of training.

When comparing this study with Jackson et al. 2007 it is found that this study has additional testing. This study has a twenty-minute performance test as well as the lactate profile and VO_{2max}- test and the strength tests. Jackson et al. 2007 used lactate profile and a time-to-exhaustion test, evaluating cycling economy, lactate levels and time to fatigue.

Admittedly, the author failed to retrieve all training logs from the subjects, which makes it impossible to calculate correlation between important variables like Watt/kg or VO_{2max} with training hours spent in different intensity zones or total training hours per week. Another important factor are the subjects amount of training hours during the intervention. The changes from pre- to post-test could be explained with the fact that the two intervention groups had more training than the control group. So if someone should repeat the study, adding an additional cycling only group with the same amount of training as the intervention groups to even out differences in the amount of training.

5.0 Practical applications

In the present study all groups bettered their performance regarding previous stated findings. The study found that heavy resistance training as well as high repetition resistance training, in percentage from pre- to post-test improved performance in cycling of highly trained veteran cyclists more than the control group. This is in agreement with several other studies (Millet et al. 2009, Raastad et al 2009, Støren et al 2008 and Sunde et al 2010) finding that heavy resistance training improves performance in different endurance sports.

Furthermore, data existing on technique from the performance test, body composition measures and the subjects training logs, would be interesting to investigate further.

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