Abstract

The purpose of the present study was to investigate the effects of upper body strength training on work economy and muscle O_2 saturation (SmO_2) during prolonged double poling exercise. Twentynine national level cross-country skiers were assigned to either a group with added strength training (STR; n=19) or a control group (CON; n=8). Strength tests consisted of 1 RM in lat pulldown, bench pulls and triceps press. Conditioning tests were split into 4 days of testing (2 pre, and 2 post), where day 1 and 3 consisted of a strength test, lactate profile test and VO_2max test, while day 2 and 4 consisted of a 90-minute continuous double poling test, a lactate profile test and VO_2max test. During all tests, measurements of VO_2, HR, La^-, RER, and RPE was tested. NIRS was measured on 3 muscles simultaneously (m. triceps brachii, m. latissimus dorsi and m. vastus lateralis), and was mounted directly on top of the muscles, attached with adhesive cloth and a bandage. The strength training performed by STR consisted of three upper body exercises, lat pulldown, latissimus pulls and triceps press, executed periodically over 8 weeks or a total of 19-24 sessions. STR increased in all three exercises (all $p<0.01$), while no change occurred in CON. Both STR and CON showed a reduction in oxygen consumption during the 90 min test from pre to post ($p<0.05$), while only CON had an increase in RER from pre to post test ($p<0.05$). No changes in La^-, HR and RPE was found. NIRS showed no significant changes from pre to post test. However, STR group showed a stable development in SmO_2 during the 90-minute test from pre to post, while the CON group had a more negative development from pre to post test, reflecting the RER results to some degree.

The study concluded that strength training had no positive effect on any endurance related variables during prolonged double poling, but also no negative effect either. Only the CON group had a increase in RER, which indicates an increase in effort even when all other variables in the test stayed the same. SmO_2 showed similar tendencies, although not significant, that the CON group had more negative development in SmO_2 from pre to post test. This study showed that added strength training not always gives an increase in work economy during prolonged double poling at moderate intensity, and that strength training might participate in preventing negative effects to RER and SmO_2 caused by endurance training alone.

Preface

This study has been a part of larger project conducted at Høgskolen i Lillehammer. The whole project elaborated around the same test procedures as described in this study, but also using the other tests (VO2max and lactate profile) in their analysis, to look at both performance variables and physiologic variables in these subjects. The study also included EMG measurement during test day 2 and 4. A strength test for testing explosive properties was conducted before the 1RM strength test, but due to inconsistent measurements, the data could not be used. The study was supervised by 1 professors, and 1 Phd student, while 2 master thesis students and 3 bachelor thesis students were included in the study. I was involved shortly before the testing period, and was therefore not included in the planning phase of the project.

Acknowledgement

I would like to thank my supervisor Mireille van Beekvelt for her excellent advisory, great knowledge and help with forming this thesis. Further I would like to thank Bent Rønnestad, Daniel Hammarstrøm and Høgskolen in Lillehammer for making this project possible, together with lab assistants Joar Hansen and Torstein Eriksen. I would also send a confirmed thanks to my coworkers during the project, master student Sjur Øfsteng and bachelor students Sylvi Sommer, Håkon Raaness and Marius Aastad. Furthermore I would like to thank my mother and father for the support during a difficult time, and my girlfriend Dina Berg for having persevered with me during this process.

Table of contents

Introduction

Long distance cross country skiing has been getting an increasingly higher interest amongst athletes and in media, both in the international, and national arena. With the establishment of the FIS marathon cup, it has been a blooming of private teams and cross country skiers who choose to compete at a professional level, due to the increased interest. In contrast to traditional cross country races, where the race time is usually less then 60 minutes, the duration of a long distance cross country race is that the racing time is rather long, somewhere between 2,5-4 hours. Additionally, in many of the races much more of the distance is performed with the double poling technique compared to traditional races. This has lead to an increase in specific double poling training, which also emphasize the importance of work economy. Because of the relatively new focus on the long distance part of the sport, few of the physiological properties of these athletes have been mapped.

In recent years, studying the effect of combined strength and endurance training has been a popular research topic in general. Research found that by increasing 1 repetition maximum (1RM) in various leg exercises, had a positive effect on work economy in both running and cycling endurance, without any change in VO_2max, nor any change in muscle circumference (Hickson et al., 1988). Other researchers have also found similar results, and not only by increasing 1RM in the legs, but also that increased 1RM in upper body muscles, can lead to an increase in work economy in double poling (Hoff et al., 1999, Millet et al., 2002, Østerås et al., 2002, Rønnestad et al., 2011, Rønnestad et al., 2012b). Although most studies showed a positive effect of strength training on work economy, other studies showed a lack of increase in work economy due to strength training. In the mid 90` some researchers found substantial increases in strength, but no changes in any endurance parameters (Nakao et al., 1995, Bishop et al., 1999). It was also found that endurance training was inhibiting or interfered with strength development, nevertheless strength training did not affect any endurance parameters (Hennessy and Watson, 1994, Kraemer et al., 1995). This indicates that an increase in endurance performance due to strength training is not likely to occur in every occasion.

Cross-country skiing, and especially long distance, seems to be more dependent on upper body power, and Hoff et al. (2002), showed that by increasing 1RM strength in upper body specific exercises directed towards cross country skiing, increased performance and work economy. Time to peak force in a series of 24 pulldowns at 60 % of 1RM was reduced by as much as 50-60 % at this sub maximal workload, indicating a change in explosive properties, and that it might be a contributing factor to increased work economy. This is also supported by (Hoff et al., 1999, Østerås et al., 2002, Losnegard et al., 2011)

Prior to this study, Issuring and Tenenbaum (1999), found that by adding vibration to a strength exercise (bilateral biceps curl), significantly increased the immediate effect in both mean power and max power produced by a muscle in a strength exercise, both in elite power sport athletes and amateur level power sport athletes. This was supported by Rønnestad, et al. (2012a), who found that whole body vibration increased peak power, but had no effect on 1RM strength in powerlifters. The effects of added vibration to strength training seems to be related to the explosive properties of the muscle, when studies often show results in these parameters (Rønnestad, 2004, Cormie et al., 2006). The explosive properties of a muscle due to its neuromuscular characteristics seem to have a influence on work economy, since by implementing explosive strength training to endurance training led to increased running economy (Paavolainen et al., 1999). This statement is supported by Spurrs et al. (2003), who studied the effect of plyometric training on distance running, and reported an improved performance in 3km running, and Mikkola et al. (2007), whom also found increased work economy due to added explosive strength training. This information indicates that by adding vibration to heavy strength training it might be possible to get increases in explosive abilities and therefore alter the work economy even more. In a review by Nordlund and Thorstensson (2007), it was reported that adding vibration to strength training gave minor to no additional effects, but even so the report show that the potential effects of added vibration was situated around the explosive properties of the muscle, and that even if the effect might be small, it could be significant for top level athletes.

The assumption is that work economy improves due to increased 1RM, and that by adding vibration there could also be an alteration in the explosive abilities in the muscles to further improve work economy. In addition, by measuring local O_2 saturation (SmO_2 (%)), we investigate how this work economy improvement relates to changes in upper and lower body muscle saturation. This can be done with a non invasive technique called near infrared spectroscopy (NIRS). In this study, hence the focus on long distance double poling, to investigate local oxygenation in the upper body.

The aim of the study, was therefore to investigate the effect of upper body strength training on work economy and muscle O_2 saturation during prolonged double poling exercise. In addition, we will investigate if there is a superior effect of adding vibration to strength training on work economy and muscle O_2 saturation during prolonged double poling exercise.

Methods

Subjects

Twentynine male national level cross-country skiers participated in this study. The study was carried out prior to the competition season. The study consisted of 4 test days, 2 prior to the intervention period (pre-test) and 2 following (post-test). The intervention period was set to eight weeks of training. The subjects were informed about the project, both content and timespan, but did not receive any information about the different hypotheses of the study. All subjects signed an informed consent, approved by the Human Research Review Committee before study start. A main selection criteria was that the subjects were national level cross-country skiers or long distance experts. Since these subjects are national level skiers, previous strength training experience was not taken in to account. The subjects were counterbalanced into three training groups, a traditional resistance training group (ST), a resistance training group with added vibration (ST+), and a control group (CON). Criteria for exclusions were that the subjects participating, had to undergo 80 % of the scheduled training sessions, and participate on both pre and post tests. This resulted in the exclusion of two subjects in the ST+ group, who did not part in the post test due to illness. The physical character of the subjects are presented in table 1.

Table 1. Anthropometric data of test subjects. ST being traditional strength, ST+ being strength group with added vibration, and CON the control group.Values are presented as means ± SD

	ST (10)	ST+ (9)	CON (8)	p-value
Age mean (years)	22,3 ± 2,1	23,8 ± 5,8	26,8 ± 6,5	0,214
Hight mean (cm)	183,9 ± 8,1	181,9 ± 7,0	183 ± 6,9	0,915
Weight pre mean (kg)	78,32 ± 7,6	77,64 ± 8,03	76,54 ± 7,48	0,852
Vo2 max	69,64 ± 5,95	67,63 ± 4,23	66,35 ± 7,55	0,508
HRmax	192,7 ± 11,40	193,7 ± 7,12	183,13 ± 8,89	0,068
Weight post mean (kg)	78,16 ± 7,43	77,91 ± 8,25	76,66 ± 7,39	0,914
training hours last year	647 ±153,99	631,55 ± 104,34	530,5 ± 202,2	0,334
Strength training last year	31,63 ± 17,52	26,6 ± 19,81	24,4 ± 20,8	0,766

Pre and post testing

As shown in figure 1 (only showing test day 1 and 2), all subjects went through 4 days of testing, which included 3 strength exercise tests and 2 double poling conditioning tests on day one, and 3 double poling conditioning tests on day two. Test day 3 and 4 were identical to test day 1 and 2. All subjects used the same type of roller skis (Swenor fiberglass, Sport import AS, Sarpsborg, Norway), with the same type of wheels (Swenor wheels type 2, Sport import AS, Sarpsborg, Norway), delivered by us. All subjects could use their own poles and shoes. Day 1 (pre) consisted of 1 RM strength tests followed by 1 hour pause before a lactate (La^-) profile test and VO_2max test. Day 2 (pre) consisted of a 10-minute warmup before a 90-minute long distance test, La^- test and a VO_2max test. Day 3 (post) consisted of the same tests as in day 1, and day 4 (post) the same as day 2. During the tests measurements of VO_2, La^-, RER, HR, RPE (Borg, 1982) and SmO_2 was done. VO_2, La^-, RER, HR and SmO_2 were measured during, activity, while La^- and RPE were measured standing still.

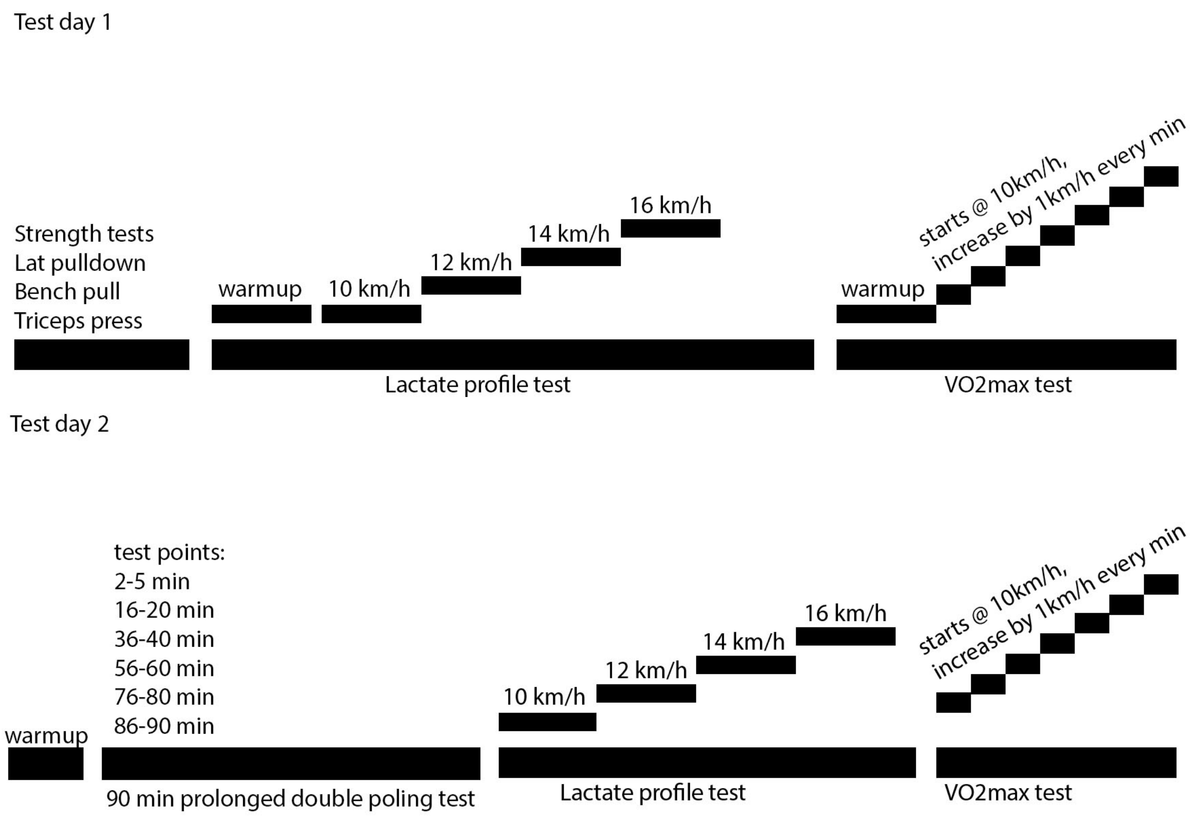

Figure 1. Schematic representation of the protocols on day 1 and day 2 of both pre- and post-tests.

Strength tests

Strength was tested prior and following the strength training program on day 1 (pre-test) and day 3 (post-test). Prior to the strength tests all subjects underwent a standardized warmup, which consisted of 5 min on a spinning cycle (Body bike classic, Body bike International AS, Fredrikshavn, Denmark) at moderate intensity, followed by 1x10 reps in four different bodyweight exercises, which included vertical jumps, sit-ups, push-ups and back extensions. This was followed by a strength specific part that included 3 sets of 10, 6, and 3 repetitions with sub max weigths in the lat pulldown exercise (Gym2000 lat pulldown 125kg, Gym2000 AS, Vikersund, Norway). The actual strength tests consisted of three exercises; a lat pulldown, a bench pull and a triceps press, all which were conducted in a standard manner, with no excessive movement in the body. All athletes were given up to 6 attempts in each exercise in above mentioned order, to reach their 1RM. The percentage change in 1RM (Δ1RM (%)) from pre- to post-test was used for data analysis.

Lactate profile test

A lactate profile test was done on all test days, but only the one on day 1 was used in this study, because it was related to the speed in the 90-minute test. The lactate profile test was done on a special treadmill (Rodby RL2500E x 1000, Rodby, Sodertalje, Sweden), which was extra wide, and long to support double poling. The treadmill was set to an inclination of 6 %, and the starting pace was 10 km/h, and was increased with 2 km/h for every block, which lasted for 5 minutes. During this test, SmO_2, VO_2, La^-, HR and RPE were measured. SmO_2 was measured continuously throughout the whole test, while VO_2 was measured between minute 2-5 of each work rate. La^-, HR and RPE was measured between the work blocks, which gave the subject approximately 1 minute break. The test was over when the subject reached or passed 4 mmol/l of La^-. This test was used to find each subjects anaerobic threshold and the onset blood lactate accumulation (OBLA).

VO_2max test

In order to define maximum speed and VO_2 during double poling, an incremental test was done on the treadmill. The test was performed with a 6 % inclination on the treadmill, and with a starting speed of 10 km/h, increasing with 1 km/h every minute until exhaustion. During the whole test VO_2 and SmO_2 was measured, whilst La^-, HR and RPE were taken at the end of the test. Criteria for this test was a flattening of the VO_2 curve and HR curve, while a high as possible result in both La^- and RPE was preferable. In this study VO_2max was used as a part of setting the pace for the 90-minute test.

90 minute prolonged double poling test

This was a prolonged test done on the 2. day pre and post, where the subjects had to double pole for 90 minutes. The treadmill was set to 6 % inclination and the pace was determined by the subjects results on day one. A linear relationship between sub maximal VO_2 and sub maximal speeds from lactate profile test were created, and the point where 65 % of VO_2max crossed the line was the pace we used. VO_2 measurements were measured between 2-5 minutes, 16-20 minutes, 36-40 minutes, 56-60 minutes, 76-80 minutes and 86-90 minutes. SmO_2 and HR was measured continuously throughout the test, and mean values were calculated from the last minute in these measurement blocks. After each measurement block the subjects were stopped for approximately 1 minute and measurements of La^- and RPE were taken. The change (Δ) in VO_2, La^-, RER, HR, RPE and SmO_2 variables from pre- to post-test was used in statistics. During the test, the subjects were given a random quiz to keep his motivation up.

Intervention period

The intervention period consisted of 8 weeks of periodized double poling specific strength training. The prescribed training was a supplement to their regular training regiment, without decreasing the regular training hours. The strength exercises that were used were lat pulldowns, straight arm lat pulls (with a added bench in front for support) and triceps press, all conducted with a specific handle with attached loops, to simulate the poling feeling as much as possible. Both strength groups had the same exercises, apart from the ST+ group whom had added vibration to these exercises, and conducted their training on a modified lat pulldown apparatus, with an attached motor that stood for the vibration. The intervention protocol is described in table 2. The subjects had to perform at least 80 % of the training sessions with, preferably 3 sessions a week and 19-24 sessions in total. Furthermore, the instructions was to perform each exercise explosively and controlled without too

Table 2. Schematic representation of the 8 week intervention protocol showing the periodic progression model from day to day, and week to week.

	Day 1	Day 2	Day 3
week 1-3	3 sets x 10 reps (RM weight) 2 min. break between sets	3 sets x 12 reps (90% of RM) 1 minute break between sets	3 sets x 6 reps (RM weight) 3 min. break between sets
week 4-6	3 sets x 8 reps (RM weight) 2 min. break between sets	3 sets x 10 reps (90% of RM) 45 seconds break between sets	3 sets x 5 reps (RM weight) 3 min. break between sets
week 7-8	3 sets x 6 reps (RM weight) 2 min. break between sets	3 sets x 8 reps (90% of RM) 2 minute break between sets	4 sets x 4 reps (RM weight) 3 min. break between sets

much compensatory movement in the rest of the body. The CON group continued with their regular training program.

Measurements

Respiratory parameters were measured by indirect calorimetry (Jeager oxycon pro, Jaeger Instrument, Hoechberg, Germany) prior to each test day, the system was calibrated, against certified calibration gases of known concentrations. The flow turbine (Triple V, Erich Jaeger) was calibrated using a manual 3L- calibration syringe (Hans Rudolph, Kansas City, Missouri, USA). Data collected from VO_2 was measured in l/min and converted to ml/kg/min. Capillary blood lactate was analyzed from a small blood sample (20 ml) from the finger using enzymatic analysis (Biosen C-line, EKF-diagnostic GmbH, Barleben/Magdeburg, Germany). Heart rate was measured with a heart rate monitor (RS 800, Polar, Kempele, Finland), which was placed just beneath m. pectoralis major in standard manner.

Near infrared spectroscopy (NIRS) equipment was used to continuously measure the changes in local tissue saturation during all conditioning tests. NIRS is based on the tissue transparency for light in the near infrared region, and can detect changes in O_2 saturation in both hemoglobin and myoglobin, by measuring the amount of infrared light passed through tissue. It is not possible to distinguish between hemo- and myoglobin due to identical spectral characteristics. The changes in absorbed light is converted into concentration changes by using an algorithm described by Livera et al. (1991). Further the sum of both oxygenated hemoglobin and deoxygenated hemoglobin reflects the total amount of hemoglobin in the tissue (tHb), and what this study looks at is the changes in tHb during the 90-minute test, to give an impression of muscle O_2 saturation (SmO_2). The NIRS system is further described in detail elsewhere (Van Beekvelt et al., 2001). Three portable NIRS devices (Artinis Medical systems, Elst, The Netherlands) were used, and placed directly on top of the skin on top of m. triceps brachii, m. latissimus dorsi and m. vastus lateralis. All devices were attached using adhesive tape and covered with bandage. All devices generated light at 845 and 761 nm, and consisted of three LED transmitters and one receiver which is aligned on a straight line. The transmitters have a distance of 30, 35 and 40 mm from the receiver. NIRS measurements were collected using one operating system, and data sample rate was 10 Hz. Adipose tissue thickness (ATT) was measured after each test in between transmitters and receivers using a skin fold caliper (Holtain Ltd, Crym- mych, UK) to ensure that ATT was not a confounding factor. Arm and leg circumference together with weight and height were also measured. NIRS measurements was checked using MatLab_R2014b, and Δ-value calculations for SmO_2 were derived from the measurements, and further used in statistics. Furthermore VO_2, La^-, RER, HR and RPE data was compared from pre to post test, and the change in the respective variable from pre to post (Δ-values), was used in statistics.

Statistics

NIRS data was checked through several steps using Matlab_R2014b. Some data had to be removed due to low quality, especially from the device that was on top of the m. latissimus dorsi. Extreme values were checked and accounted for if considered as an abnormal measurement, to ensure normality. Statistics was done on Δ-values, using SPSS 21.0 for mac. The strength variables were tested with a standard ANOVA test. A post-hoc test within the initial anova test was used to identify if there were any significant differences between the two strength groups. VO_2, RER, La^-, HR, RPE and SmO_2 were tested using GLE repeated measurement. If Mauchly`s test showed that sphericity was violated a Greenhouse-Geisser test was used. A paired t-test was used to determine r differences within the groups when only one variable was tested. Results were accepted as significant at $P<0.05$, and are presented as means and standard deviation.

Results

In total, 29 subjects participated in this study. Two subjects in the ST+ group dropped out of the study due to sickness, and one additional subject missed scores in the strength tests (pre) due to missing data, but participated in all other tests, and all other data was used, ending up with 26 complete strength test sets, and 27 complete endurance tests. All of the 27 remaining subjects participated in at least 80 % of the training intervention.

Strength

At baseline there were no differences between any of the groups in 1RM strength in any of the three exercises (all $p \geq 0.918$). Statistics are based on percentage change in Δ1RM in the three different strength exercises. The ANOVA test showed that there was a significant difference in strength improvement between the three groups for all three exercises (all $p<0.05$). Post-hoc tests showed that ST had a significant increase in strength over the CON group in all 3 exercises (all $p<0.05$), while ST+ had significant increases in lat pulldown and triceps press (all $p<0.05$), while in no difference between ST+ and CON was found in the bench pull exercise ($p=0.137$) As shown in figure 2, compared from pre to post, 1RM strength in ST and ST+ significantly improved in all three strength exercises during the 8 week training period (all $p<0.01$), while no improvements were seen in the control group (all $p \geq 0.140$).

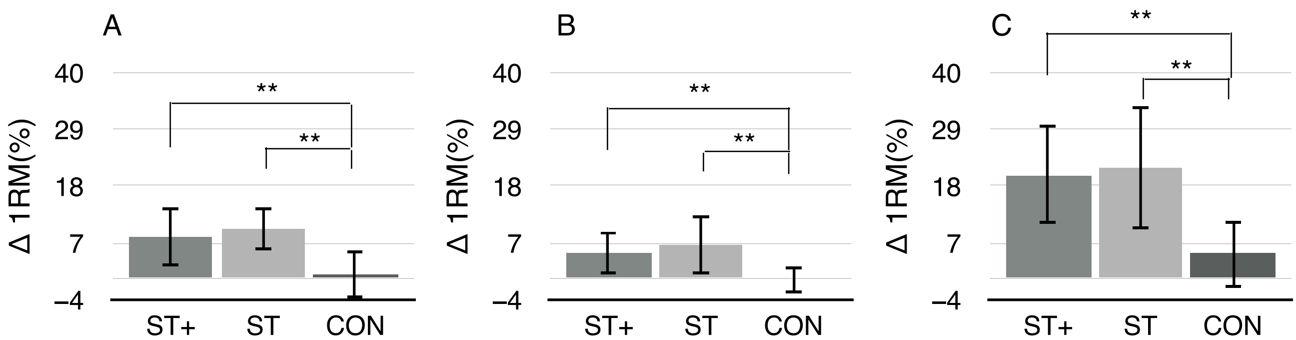

*Figure 2. Δ1 RM comparison of all 3 groups. A = lat pull, B = bench pull and C = triceps press. Percentage strength changes in 1 RM after eight weeks of strength training (ST), strength training with added vibration (ST+), or normal training (CON). Values are means ± SD, **all p>0.01.*

The increase in strength was similar for both the ST and ST+ group and there were no significant differences between the 2 groups in either of the 3 exercises (all $p=1.0$). Since the original purpose of this study was to investigate if added vibration had a superior effect over regular strength training, and since both groups showed similar improvements in strength in all three exercises, we decided to merge the two groups, and focus on the evaluation of the effect of strength training in general on prolonged endurance performance. In addition, we checked for differences in VO_2 between the two groups, but neither here found a difference for VO_2 (p=0.260). The remaining analysis was therefore done on both strength groups as one (STR) and one control group (CON).

After merging the groups, the STR group consisted of 19 subjects and the CON group of 8 subjects. There were no significant differences between the two groups either in age (p=0,09), height (p=0.95) or weight (p=0.68). Nor were there any significant differences in training status between both groups, neither in training hours over the last year (p=0,14), nor in hours pr. week after their competition season ended (p=0,86), even when comparing the last 4 days, there were no difference (p=0.83). The hours doing heavy strength training were not different either between both groups, within the same categories as mentioned above (p=0.57, p=0.09, p=0.63). Strength results at baseline showed no differences between the STR group and CON group (all p≥0.511). While the results show that the STR group had a significantly larger improvement in strength than compared to the CON group in all 3 strength exercises (all p<0.01) (figure 3). Most improvement was shown in triceps press, then lat pulldowns, then bench pulls.

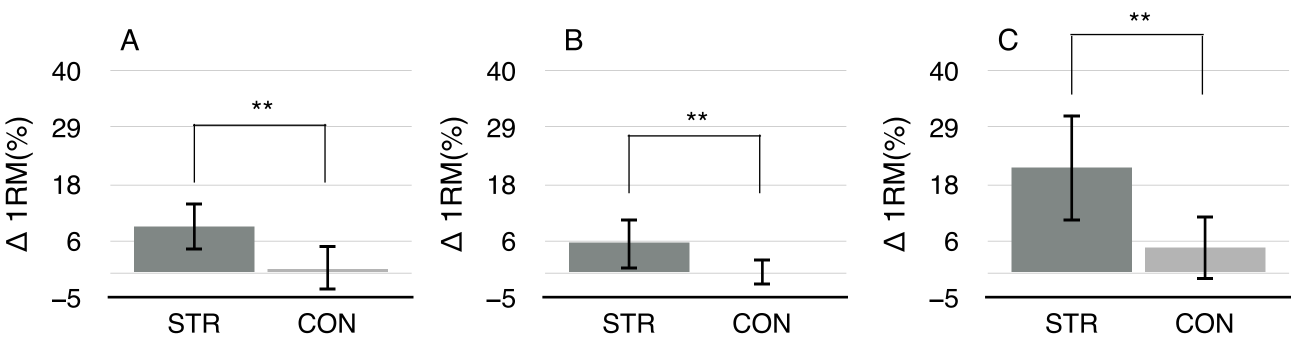

*Figure 3. Δ1RM comparison after merging ST and ST+. A = lat pull, B = bench pull and C = triceps press. Percentage strength changes in 1 RM after eight weeks of strength training (STR) or normal training (CON). Values are means ± SD, **all p>0.01.*

VO_2 measurements

The mean group response in VO_2 during the 90 min prolonged double poling test for both pre and post and the Δ-values for VO_2 for both groups are shown in figure 4. Both groups showed a similar response in VO_2 consumption during the test, where both groups had a steady increase in O2 consumption throughout the 90-minute test. No main effect of group was found for ΔVO_2 from pre to post (p=0.998), indicating that the change in VO_2 consumption from pre to post was similar in both groups. A main effect was found for time (p<0.01), indicating that ΔVO_2 decreased during the 90-minute test. The difference between pre-post becomes more pronounced during the 90 min test.

Post-hoc tests showed a decrease in ΔVO_2 between 20-40min ($p<0.05$) and 60-80min ($p=0.068$). No interaction effect between time and group was found ($p=0.797$), indicating that both groups showed similar response in VO_2 consumption from pre to post during the test.

HR measurements

On average HR was 130 ± 11 BPM in STR and 132 ± 13 BPM in CON at baseline, and 162 ± 14 BPM in STR and 155 ± 7 BPM in CON at the end of the 90 min prolonged double poling pretest. This was respectively 117 ± 12 BPM in STR and 117 ± 16 BPM in CON at baseline post test, and 150 ± 13 BPM in STR and 142 ± 12 BPM in CON at the end of 90-minute post test. Both groups showed a similar development in HR throughout the test, with a rapid increase in HR in the beginning, which flattens towards the end (figure 4). Figure 4 also shows ΔHR. No main effect of group was found for ΔHR ($p=0.305$), nor any effect of time ($p=0.495$), and no interaction effect between group and time in ΔHR ($p=0.772$). This indicates that ΔHR was similar in both groups and did not change/remained stable during the 90-minute test.

RER measurements

In figure 4, the mean group response for RER during the 90-minute prolonged double poling test are presented. Both groups seems to show a similar response in RER during the test, with a declining pattern throughout the 90 minutes of double poling. Whereas the STR group stayed unchanged from pre-post, the CON group did not. The CON group showed a less declining pattern at post test, while also RER being significantly increased from pre to post test (figure 4). Evaluating ΔRER from pre to post, a main effect of group was found ($p<0.05$), indicating that there were a difference in ΔRER response between groups. Post-hoc tests showed that a main effect of time was found ($p<0.05$), indicating a change in ΔRER during the test. Post-hoc testing showed changes at 60-80min ($p<0.05$) and a tendency of change at 20-40 min ($p=0.086$). Also an interaction effect was found between time and group ($p<0.05$). Post-hoc tests showed that the STR group had no change, while an increase in RER in the CON group from pre to post during the test was showed. Post-hoc test also shows that the increase in ΔRER seems to be situated in the timespan between 20-40 min ($p<0.05$) and a tendency of increase in ΔRER at 60-80 min ($p=0.08$).

La^- measurements

On average La^- was 1.51 ± 0.75/1.9 ± 0.5 mmol/l at baseline in group STR/CON, and 1.78 ± 0.7/1.67 ± 0.4 mmol/l at the end of the 90 min prolonged double poling pretest, while respectively 1.31 ± 0.31/1.54 ± 0.5 mmol/l at baseline post test, and 1.31 ± 0.37/1.27 ± 0.3 mmol/l in STR/CON at the end of the test. Both groups showed a similar development in La^- throughout the test, with a rapid increase in the beginning, and a steady descending pattern throughout the 90-minute test, as shown in figure 4 together with ΔLa^-. No main effect of group was found (p=0.874), indicating that the change in lactate from pre to post was similar in both groups. Also no effect of time was found (p=0.76), indicating no change in ΔLa^- during the 90-minute test. Interaction between group and time in ΔLa^- was also insignificant (p=0.976), indicating that the effect of group and time was similar for both groups.

RPE measurements

Similar results where found for RPE during the 90-minute prolonged double poling test for both groups, with a rather stable flat development throughout the test. STR started at 12 ± 1.2 and ended the 90 min test pre at 14.5 ± 1.15, while CON started with 12 ±1.3 and ended at 14 ± 2 at pre test. At post test STR started at 10.5 ± 1.95 and ended at 13 ± 1.5, while CON started at 12 ± 1.3 and ended the 90-minute post test at 13.5 ± 1.7. The development in RPE throughout the test showed that no main effect of group was found (p=0.542), nor any effect of time (p=0.294), nor any interaction effect between group and time (p=0.299), indicating that both groups had no change in RPE from pre to post during the test.

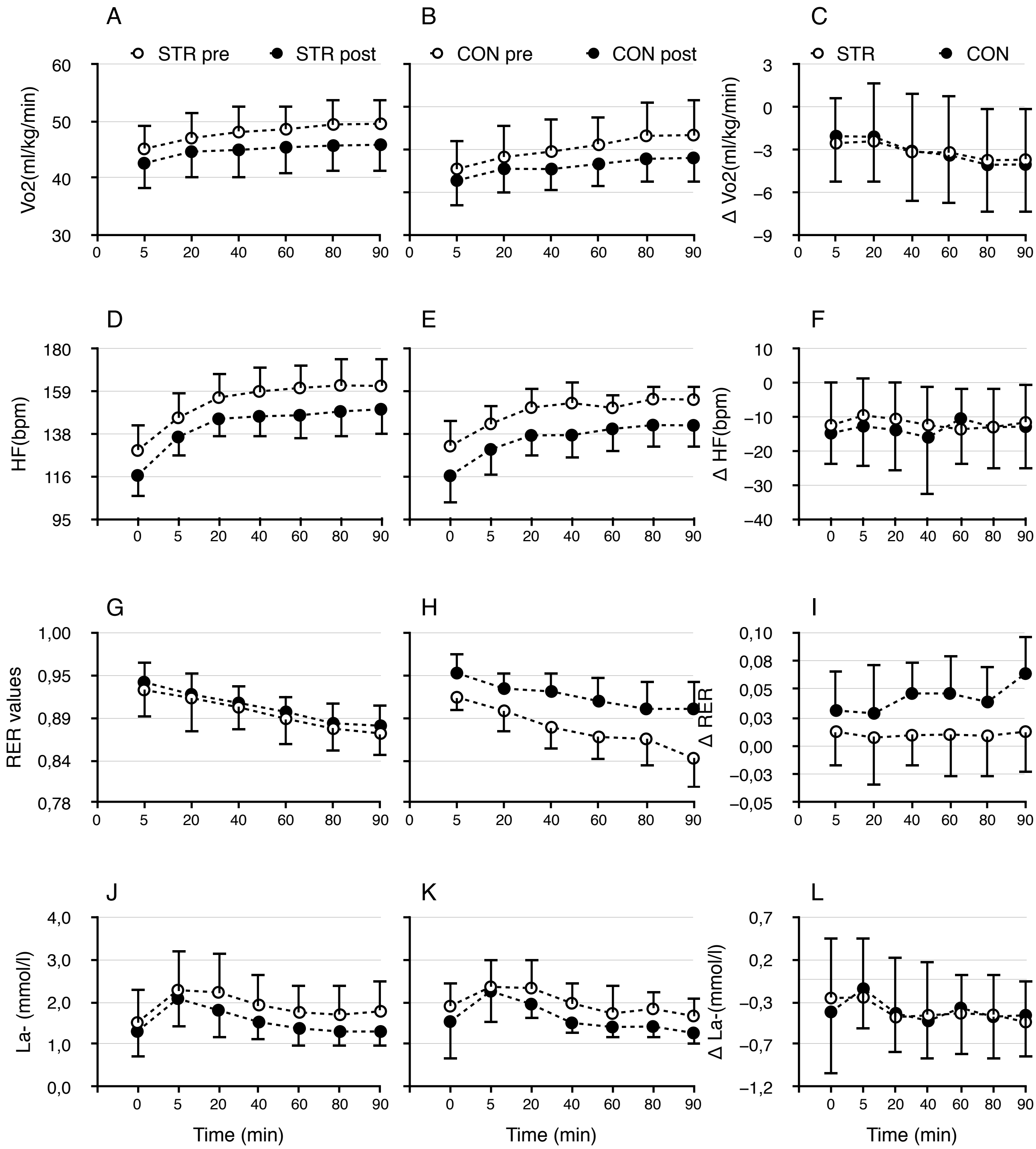

Figure 4. Mean (±SD) group response for VO_2 (A, B, C), HR (D, E, F), RER (G, H, I), and La^- (J, K, L) during 90-minute prolonged double poling test before (pre) and after (post) 8 weeks of intervention period, showing STR on the left (A, D, G, J), CON in the middle (B, E, H, K) and Δ values on the right (C, F, I, L). Values are means ± SD.

NIRS measurements

NIRS measurements was done in 3 muscles simultaneously, m. triceps brachii, m. latissimus dorsi and m. vastus lateralis. Local tissue saturation was measured in SmO_2 (%). ATT was measured after the 90-minute test, and was respectively 7.8 ± 2.9 mm pre- and 6.6 ± 2.4 mm post-test in TB, 8.1 ± 1.5 mm pre- and 6.9 ± 1.1 mm post-test in LD and 11.2 ± 4.3 mm pre- and 7.9 ± 2.7 mm in VL. The ATT was less than half the distance between the emitter and the detector in every case.

Triceps Brachii (TB)

The mean group response in SmO_2 (%) for TB during the 90 minute prolonged double poling test are shown in figure 5. Both groups showed similar response in SmO_2 during the 90 minute test. Evaluation of the ΔSmO_2 from pre to post, are shown in figure 5, with a drop in SmO_2 in the beginning for then to steadily increase throughout the test. No main effect of group ($p=0.498$), nor time ($p=0.457$), nor an interaction effect in SmO_2 between group and time was either found ($p=0.126$). This indicating similar effect for both groups during the 90-minute test.

Latissimus dorsi (LD)

The measurement on LD was most viable for measurement problems (noise, cross-talk, mounting problems), so it has to be noted that 10 full test measurements, to 10 subjects, had to be discarded due to poor quality. This might further influence the result from this device. However, the mean group response in SmO_2 (%) for LD during the 90 min prolonged double poling test are shown in figure 5, and shows roughly similar response as for TB, with some alteration in the beginning. Evaluating the ΔSmO_2 from pre to post (figure 5), show that no main effect of group was found ($p=0.378$), nor any effect of time ($p=0.650$). The interaction effect between group and time in SmO_2 was also not significant ($p=0.310$), which indicates no changes in SmO_2 in either groups from pre to post in the 90-minute test.

Vastus Lateralis (VL)

On VL, the mean group response in SmO_2 (%) during the 90 min prolonged double poling test are shown in figure 5, and both groups showed a rather similar response in SmO_2 during the test, with very little desaturation. Both groups shows a rather straight line in development, but while STR group show a more stable variation, the CON group has a more unstable variation. Evaluation of the ΔSmO_2 from pre to post are shown in figure 5, and no main effect of group was found ($p=0.905$). However a main effect of time was found ($p<0.05$), and post-hoc test shows that the changes seems to be situated between 20-40 min ($p<0.05$), 40-60 min ($p<0.05$) and 80-90 min ($p<0.05$). Further looking at the interaction of group and time in SmO_2 an effect was found ($p<0.05$), this indicating that both groups have different response in SmO_2 from pre to post during the test. The changes seems to occur between 20-40 min ($p<0.05$) and 80-90 min ($p=0.056$). Although an effect was found, figure 5 shows that the reason might be due to how the two groups had different developments throughout the 90-minute test.

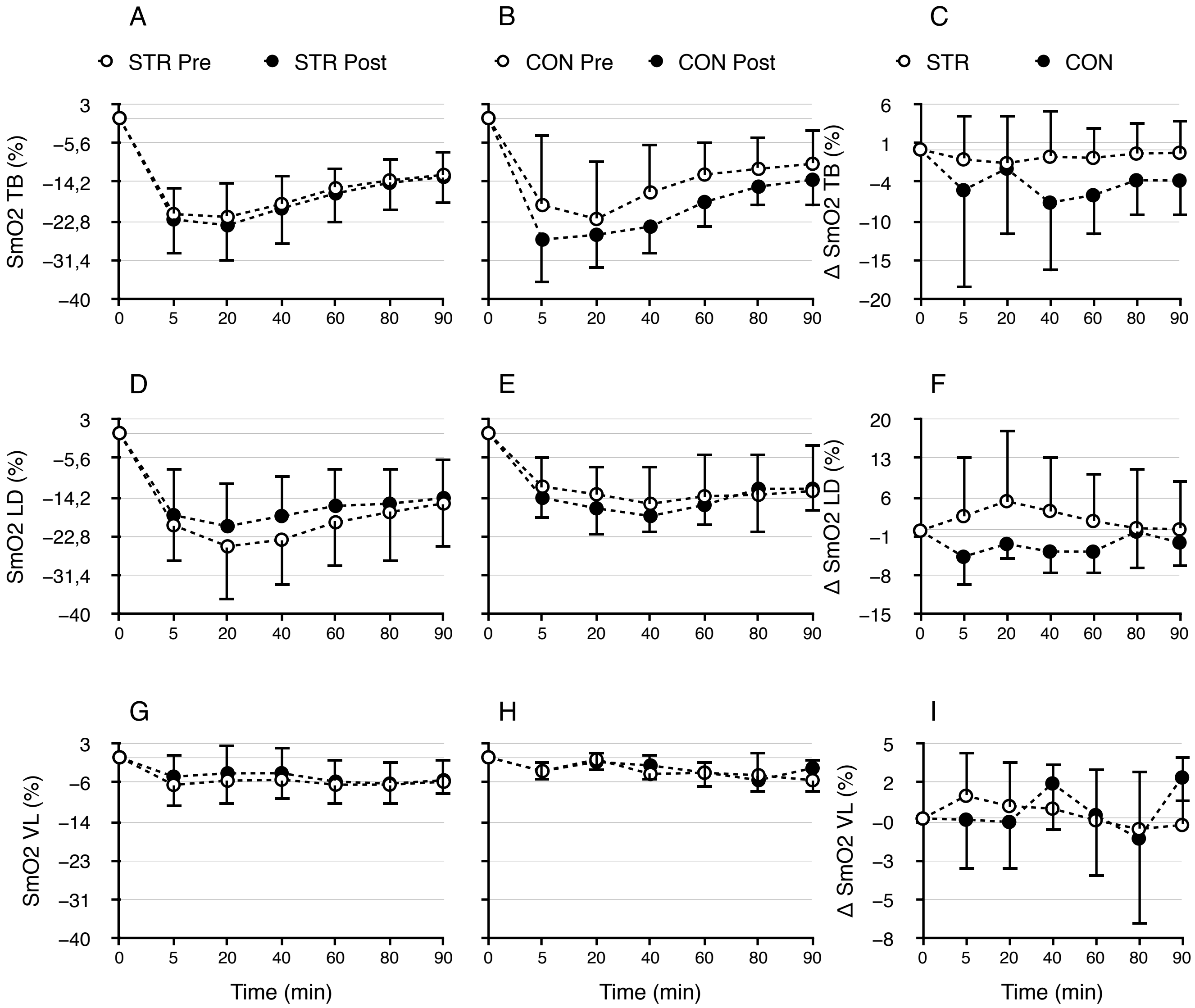

Figure 5. Mean (±SD) group response for SmO_2 (%) in the m. triceps brachii (TB) (A, B, C), m. latissimus dorsi (LD) (D, E, F) and m. vastus laterlis (VL) (G, H, I) during 90 minute prolonged double poling test before (pre) and after (post) 8 weeks of intervention period, showing STR on the left (A, D, G), CON in the middle (B, E, H) and Δ values on the right(C, F, I). Values are means ± SD.

Discusion

The purpose of this study was to investigate the effect of upper body strength training on work economy and muscle O_2 saturation (SmO_2 (%)) during prolonged double poling exercise. In addition, see if vibration gave a superior effect over regular strength training in both work economy and SmO_2. The main findings of this study were that heavy strength training increased 1RM in all three exercises, and no negative effect on the systemic variables VO_2, RER, La^-, HR and RPE, nor on SmO_2. An increase from pre- to post-test in RER in the CON group was found, indicating a change in energy consumption in the CON group, towards a higher anaerobic energy release, and a increased use of carbohydrates during the 90-minute test as a result.

The second aim of the study was to see if adding vibration to strength training gave a superior effect on both work economy and SmO_2, and in order to test this we used 3 groups; 2 strength groups and 1 control group. One traditional strength group (ST) and one with added vibration (ST+). When comparing the two strength groups, both strength groups had an increase in 1RM strength in all three exercises over the CON group, but no differences was found between the two strength groups. Hoff et al. (2002) and Østerås et al. (2002) found that by increasing 1RM strength in male cross-country skiers, an increase in work economy occurred. Increased work economy was also found when increasing 1RM in female cross-country skiers (Hoff et al., 1999). This is also supported from other sports such as cycling and running (Millet et al., 2002, Rønnestad et al., 2011). Furthermore, by adding vibration to strength training, a superior effect on work economy might occur, because of the neurological effects it imposes on the muscle (Issurin and Tenenbaum, 1999). Unfortunately we could not find any superior effects of adding vibration to strength training on 1RM strength, and when comparing VO_2 consumption during the 90-minute test between the two strength groups, we also found no differences. When no differences in 1RM strength, nor work economy was found between the strength groups, no effect was to be expected on a local level. Possible explanations that vibration had no effect could be due to the equipment. The transfer of vibration through a cable could have reduced the force of the vibration and hence the effect. Another explanation could be that the upper body is not that sensitive to vibration stimulus and that a more powerful vibration is needed. Anyhow, due to these circumstances we decided to merge the two groups into one strength group (STR).

After the merge it was clear that the new STR group had significant increase in strength in all three exercises, no change was found in the CON group. The increase in strength was respectively 9,1 ± 4,9 % in lat pulldown, 5,8 ± 5 % for bench pull and 20,9 ± 10,6 % in triceps press. Normally a 40 % increase in 1RM is observed in untrained subjects in a 12 week strength training program (Kraemer et al., 2002). However, large amounts of endurance training might have an inhibiting effect on strength development, and the expected increase in strength can be reduced to between 10-40 % due to simultaneous strength and endurance training (Hennessy and Watson, 1994, Kraemer et al., 1995, Bell et al., 2000, Millet et al., 2002, Losnegard et al., 2011). Another factor is that the intervention period in this study was 8 weeks, and not 12, which reduces training time, and therefor can affect strength development, and further explain why some of the strength exercises in this study had lower strength increases.

Although there was an increase in strength, there were no changes between the groups in any of the endurance variables during the 90-minute test, including VO_2, La^-, HR, RPE, except for RER. A slight decrease in VO_2 consumption was found in both groups during the test from pre to post, indicating that both groups had a positive development in work economy. This was expected since most research have found a positive relation between strength training and work economy (Hoff et al., 2002, Østerås et al., 2002, Storen et al., 2008). Although, what we did not expect was that the CON group had a similar development in work economy as the STR group. This showed that an increase in work economy can occur with or without added strength training, and that added strength training not always gives a superior increase in work economy. Further looking at La^-, HR, and RPE, research has shown that added strength training to endurance training has variable influence on these parameters, with some finding decreases (Rønnestad et al., 2011), and some not (Østerås et al., 2002, Rønnestad et al., 2012b). In this study these parameters did not change from pre to post due to included strength in both groups.

RER showed a stable decline during the 90-minute test in both groups in the pre test, however, the post test showed that the STR group had a similar declination as in the post test, while the CON had a higher and less declining development at post test. As can be seen in figure 4, it seems that most of the change is located in the CON group and that they had an increase from pre to post. Higher RER values indicates that the CON group had a metabolic change towards a higher anaerobic energy release, which contributes to a higher use of carbohydrates as energy, which is related to increased energy expenditure. Also, as mentioned above, that large amounts of endurance training can inhibit strength development (Hennessy and Watson, 1994, Kraemer et al., 1995, Millet et al., 2002, Losnegard et al., 2011), it could also mean that without strength training, a decrease in muscular strength could happen, and that the subjects need to use more force and energy to keep up with the given intensity. This can indicate that strength training not only increases strength, but possibly might prevent other negative effects of endurance training, such as increased RER, and further keeping a more optimal metabolic environment for prolonged endurance exercise. Although this is only speculation, this could be subject for future research.

In this study we used the NIRS system to look at SmO_2 during the 90-minute test. Other studies have recently used NIRS measurements in both running (Buchheit et al., 2010, Ihsan et al., 2013, Jones et al., 2013, Ufland et al., 2013) and cycling (Racinais et al., 2007, Smith et al., 2012, Billaut and Buchheit, 2013) studies. There has also been done one study on upper body repeated sprint in highly trained individuals (Sandbakk et al., 2015). However, this is the first study to incorporating NIRS to investigate physiological responses in mainly upper body muscles during prolonged upper body endurance performance. Unfortunately, and unexpectedly there was no effect of strength training on work economy. Because the lack of effect of strength training, we did not expect to see any difference in SmO_2, and not surprisingly, we did not. Nevertheless this study shows response during prolonged double poling exercise in 3 simultaneous measured muscles. The response in both upper body muscles had similar developments, with a decline in SmO_2 to 20 minutes, and then a steady increase throughout the test. This means that SmO_2 increases/normalizes during long term work, and that it might be beneficial with a longer warmup, to avoid a large decrease in SmO_2 in the beginning of exercise. Ihsan et al. (2013) found similar development in lower body muscles during 30 min continuous running, with a rapid decline in SmO2 in the beginning, and then a steady increase throughout the test. Anyhow, the development in SmO_2 reflects the development in RER to some degree. In general when RER goes down, the SmO_2 goes up, which is natural because RER reflects what kind of metabolic energy system mainly and partially being used, and further reflect the strain put on the working muscles. Therefor will a lower RER result in increased SmO_2 due to lower strain on the muscle. In both the TB and LD measurements, there were an increase in SmO_2 when RER went down, with the exception of the initial phase, where SmO_2 had a steady decline. Although there were no significant findings, it was possible to see a difference in the development in SmO_2 between pre an post testing in the two groups. The STR group showed a rather similar development throughout the 90-minute test comparing pre and post test. The CON group on the other hand showed a decrease in SmO_2 from pre to post during the test, also reflecting what happens in RER, that there were put a larger strain on the working muscles, decreasing local blood flow.

The vastus lateralis (VL) had a more stable development throughout the test, with much less desaturation compared to the upper body muscles, which is natural, due to the nature of the exercise being upper body dominant. Further the VL measurements show significant differences during the test from pre to post. These differences occur most likely because the STR group have a stable, and rather flat development in SmO_2 throughout the 90-minute tests, while the CON group show a inconsistent pattern, where the graph has more variation both up and down. However, we consider this difference mainly to occur because of the inconsistent pattern in SmO_2 in the CON group.

The development in TB and LD could mean that without supplemental strength training a decrease in SmO_2 might occur, and that this could be one of the mechanisms involved in the increase of work economy due to added strength training. If the training period had a longer timespan, maybe the differences might have been larger, and possibly significant. Even if the graphs show tendencies of change from pre to post, most of them are not significant, and only indications that this should be a topic worth looking into in future research.

In conclusion, the aim of this study was to investigate the effect of upper body strength training on work economy and SmO_2 during prolonged double poling, and to see if adding vibration had an additional effect on 1RM strength, work economy and SmO_2. We found that adding vibration to strength training had no effect on 1RM strength, nor any superior effect over regular strength training on work economy during a long distance endurance test. Also, we found no effect of strength training on any endurance related variables, both systemic and local, apart from RER. We found an increase in RER in the CON group in the post test, possibly indicating that strength training might play a role in preventing negative changes in various endurance parameters. Even if there were not many findings in this study it is important to notice that all other systemic variables tended to go in a positive direction in both groups. NIRS showed no statistical significant differences in either TB, nor LD measurements. However, the graphs showed tendencies towards a reduced SmO_2 in the CON group in post test. NIRS data seems to show similar tendencies as found in RER, and this only being speculations, there might be an effect of strength training that prevents negative developments in both RER and SmO_2 during prolonged endurance exercise.

References

BELL, G., SYROTUIK, D., MARTIN, T., BURNHAM, R. & QUINNEY, H. 2000. Effect of concurrent strength and endurance training on skeletal muscle properties and hormone concentrations in humans. European Journal of applied physiology, 81, 418-427.

BILLAUT, F. & BUCHHEIT, M. 2013. Repeated-sprint performance and vastus lateralis oxygenation: Effect of limited O2 availability. Scandinavian journal of medicine & science in sports, 23, e185-e193.

BISHOP, D., JENKINS, D. G., MACKINNON, L. T., MCENIERY, M. & CAREY, M. F. 1999. The effects of strength training on endurance performance and muscle characteristics. Medicine and Science in Sports and Exercise, 31, 886-891.

BORG, G. A. 1982. Psychophysical bases of perceived exertion. Med sci sports exerc, 14, 377-381.

BUCHHEIT, M., BISHOP, D., HAYDAR, B., NAKAMURA, F. Y. & AHMAIDI, S. 2010. Physiological responses to shuttle repeated-sprint running. Int J Sports Med, 31, 402-409.

CORMIE, P., DEANE, R. S., TRIPLETT, N. T. & MCBRIDE, J. M. 2006. Acute effects of whole-body vibration on muscle activity, strength, and power. The Journal of Strength & Conditioning Research, 20, 257-261.

HENNESSY, L. C. & WATSON, A. W. 1994. The interference effects of training for strength and endurance simultaneously. The Journal of Strength & Conditioning Research, 8, 12-19.

HICKSON, R., DVORAK, B., GOROSTIAGA, E., KUROWSKI, T. & FOSTER, C. 1988. Potential for strength and endurance training to amplify endurance performance. J Appl Physiol, 65, 2285-90.

HOFF, J., GRAN, A. & HELGERUD, J. 2002. Maximal strength training improves aerobic endurance performance. Scandinavian journal of medicine & science in sports, 12, 288-295.

HOFF, J., HELGERUD, J. & WISLØFF, U. 1999. Maximal strength training improves work economy in trained female cross-country skiers. Medicine and Science in sports and Exercise, 31, 870-877.

IHSAN, M., ABBISS, C. R., LIPSKI, M., BUCHHEIT, M. & WATSON, G. 2013. Muscle oxygenation and blood volume reliability during continuous and intermittent running. Int J Sports Med, 34, 637-45.

ISSURIN, V. & TENENBAUM, G. 1999. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. Journal of sports sciences, 17, 177-182.

JONES, B., HESFORD, C. M. & COOPER, C. E. 2013. The use of portable NIRS to measure muscle oxygenation and haemodynamics during a repeated sprint running test. Oxygen Transport to Tissue XXXV. Springer.

KRAEMER, W. J., ADAMS, K., CAFARELLI, E., DUDLEY, G. A., DOOLY, C., FEIGENBAUM, M. S., FLECK, S. J., FRANKLIN, B., FRY, A. C. & HOFFMAN, J. R. 2002. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Medicine and science in sports and exercise, 34, 364-380.

KRAEMER, W. J., PATTON, J. F., GORDON, S. E., HARMAN, E. A., DESCHENES, M. R., REYNOLDS, K., NEWTON, R. U., TRIPLETT, N. T. & DZIADOS, J. E. 1995. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. Journal of applied physiology, 78, 976-989.

LIVERA, L. N., SPENCER, S. A., THORNILEY, M. S., WICKRAMASINGHE, Y. & ROLFE, P. 1991. Effects of hypoxaemia and bradycardia on neonatal cerebral haemodynamics. Archives of disease in childhood, 66, 376-380.

LOSNEGARD, T., MIKKELSEN, K., RØNNESTAD, B. R., HALLÉN, J., RUD, B. & RAASTAD, T. 2011. The effect of heavy strength training on muscle mass and physical performance in elite cross country skiers. Scandinavian journal of medicine & science in sports, 21, 389-401.

MIKKOLA, J. S., RUSKO, H. K., NUMMELA, A. T., PAAVOLAINEN, L. M. & HÄKKINEN, K. 2007. Concurrent endurance and explosive type strength training increases activation and fast force production of leg extensor muscles in endurance athletes. The Journal of Strength & Conditioning Research, 21, 613-620.

MILLET, G. P., JAOUEN, B., BORRANI, F. & CANDAU, R. 2002. Effects of concurrent endurance and strength training on running economy and VO~ 2 kinetics. Medicine and science in sports and exercise, 34, 1351-1359.

NAKAO, M., INOUE, Y. & MURAKAMI, H. 1995. Longitudinal study of the effect of high intensity weight training on aerobic capacity. European journal of applied physiology and occupational physiology, 70, 20-25.

NORDLUND, M. & THORSTENSSON, A. 2007. Strength training effects of whole-body vibration? Scandinavian journal of medicine & science in sports, 17, 12-17.

PAAVOLAINEN, L., HÄKKINEN, K., HÄMÄLÄINEN, I., NUMMELA, A. & RUSKO, H. 1999. Explosive-strength training improves 5-km running time by improving running economy and muscle power. Journal of Applied Physiology, 86, 1527-1533.

RACINAIS, S., BISHOP, D., DENIS, R., LATTIER, G., MENDEZ-VILLANEUVA, A. & PERREY, S. 2007. Muscle deoxygenation and neural drive to the muscle during repeated sprint cycling. Medicine and science in sports and exercise, 39, 268.

RØNNESTAD, B. R. 2004. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. The Journal of Strength & Conditioning Research, 18, 839-845.

RØNNESTAD, B. R., HANSEN, E. A. & RAASTAD, T. 2011. Strength training improves 5-min all-out performance following 185 min of cycling. Scandinavian journal of medicine & science in sports, 21, 250-259.

RØNNESTAD, B. R., HOLDEN, G., SAMNØY, L. E. & PAULSEN, G. 2012a. Acute Effect of Whole-Body Vibration on Power, One-Repetition Maximum, and Muscle Activation in Power Lifters. The Journal of Strength & Conditioning Research, 26, 531-539.

RØNNESTAD, B. R., KOJEDAL, Ø., LOSNEGARD, T., KVAMME, B. & RAASTAD, T. 2012b. Effect of heavy strength training on muscle thickness, strength, jump performance, and endurance performance in well-trained Nordic Combined athletes. European journal of applied physiology, 112, 2341-2352.

SANDBAKK, Ø., SKÅLVIK, T. F., SPENCER, M., VAN BEEKVELT, M., WELDE, B., HEGGE, A. M., GJØVAAG, T. & ETTEMA, G. 2015. The physiological responses to repeated upper-body sprint exercise in highly trained athletes. European journal of applied physiology, 1-11.

SMITH, K. J., BILLAUT, F., ARGUS, C. K., GILL, N. D., KEOGH, J. W., MCGUIGAN, M. R., HOPKINS, W. G., BUCHHEIT, M., SIMPSON, B. M. & PELTOLA, E. 2012. Tissue oxygenation in men and women during repeated-sprint exercise. Int J Sports Physiol Perform, 7, 59-67.

SPURRS, R. W., MURPHY, A. J. & WATSFORD, M. L. 2003. The effect of plyometric training on distance running performance. European journal of applied physiology, 89, 1-7.

STOREN, O., HELGERUD, J., STOA, E. M. & HOFF, J. 2008. Maximal strength training improves running economy in distance runners. Medicine and science in sports and exercise, 40, 1087.

UFLAND, P., AHMAIDI, S. & BUCHHEIT, M. 2013. Repeated-sprint performance, locomotor profile and muscle oxygen uptake recovery: effect of training background. International journal of sports medicine, 34, 924-930.

VAN BEEKVELT, M. C. P., COLIER, W. N. J. M., WEVERS, R. A. & VAN ENGELEN, B. G. M. 2001. Performance of near-infrared spectroscopy in measuring local O2 consumption and blood flow in skeletal muscle.

ØSTERÅS, H., HELGERUD, J. & HOFF, J. 2002. Maximal strength-training effects on force-velocity and force-power relationships explain increases in aerobic performance in humans. European journal of applied physiology, 88, 255-263.