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# Effect of resistance on performance in double poling

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## **Abstract**

The purpose of this study was to investigate what effect resistance would have on performance in double poling, with focus on power output, physiological responses and myoelectric activation. 6 elite male cross country skiers were exposed to simulated double poling in a Concept II Ski Ergometer at two different resistances, respectively low and high. The major findings were that power output significantly increased with the higher resistance, as well as work per cycle. These findings are previously shown in earlier research. Cycle rate remained unchanged, while stroke time increased. Earlier studies have confirmed that stroke time increase at added resistance or incline, to utilize a longer period of the cycle time to produce the required force to overcome the resistance or incline. Gross efficiency did not differ between the resistances, and no significant changes in electromyography activity were present. The increase in power output and work per cycle was therefore not attributed to an increased muscle activity. The main findings in this study are therefore inconclusive, and the increase in power output and work per cycle could be caused by other factors, such as muscle coordination and timing or changes in technical execution.



## **Introduction:**

Cross country skiing is regarded as one of the most demanding endurance sports (Saltin, 1997) and consists of two styles; the classical style and the free style. In the classical style, there are three main techniques, namely; diagonal, double pole and double pole with kick. Over the last two decades, double poling (DP) have become a main classical technique during cross country ski races (Rusko, 2002; Saltin, 1997) and in classical sprint competitions; DP is the dominant technique (Stöggl et. al, 2006). The DP technique is most advantageous in the flatter parts of the race course, as it is more economical compared to other classical techniques in this terrain (Hoffman & Clifford, 1990; Pellegrini et al. 2013).

Cross country skiers are able to generate a higher mean propulsive pole force per cycle compared to the diagonal technique (Pellegrini et al. 2013). To create propulsion, the double poling technique involves a combination of the trunk and arms where the arm movement is coordinated to push the athlete forward (Nilsson et al. 2003), and a flexion in the knee joints to lower the centre of mass, thus shifting the vertical momentum of the body to the poles (Holmberg et al. 2006). This happens in a sequential order starting with hip and trunk flexors, followed by the elbow extensor Triceps Brachii and shoulder extensors.

According to Holmberg et al. (2005), there is a specific DP strategy used by better skiers, which consists of smaller joint angles, higher flexion velocities and higher pole force during a shorter poling phase. Holmberg et al (2005) measured muscle activity with surface electromyography during DP, and uncovered several key muscles which showed high activity and can be considered important prime movers for DP.

Of interest for this study, the muscles in the upper body with the highest activity in the study performed by Holmberg et al. (2005) was Rectus Abdominis (RA), Obliquus Externus Abdominis (OBL) followed by Latisissimus Dorsi (LD), Pectoralis Major (PM) and Triceps Brachii (TB). In the lower body, Vastus Lateralis (VL) and Gastrocnemius (GAS) were the most active followed by Biceps Femoris (BF).



Through one cycle, there is a sequential order to which muscles are the most active. At the start of one cycle (beginning from the second half of the recovery phase) RA and OBL have a high activity, followed by BF activating before pole plant. Directly before the pole plant, Teres Major becomes highly active, followed by the hip flexors (RF and Tensor Fascia Lata), then the shoulder extensors (PM and LD) and Gluteus Maximus. At the pole plant, TB goes from low activity to high, accompanied by a medium activation in Biceps Brachii. At the same time in the lower body, VL and Vastus Medialis have a low activation, while shortly after pole plant, BF shows medium activity levels. This study by Holmberg et al. (2005) highlights the important contribution by the upper body, as well as the contribution by the lower body during DP.

These changes have required athletes to focus more on upper body power, in order to maximize the benefits of DP (Holmberg, 2005). Stöggl et al. (2007a) found a strong relationship between DP sprint performance on a treadmill and athletes ability to exert maximal power output measured with a 4 repetition maximum (RM) test on a rollerboard testing concept apparatus. In addition, Stöggl et al. (2007b) found a strong correlation between a maximal DP speed test on a treadmill and sprint performance.

Nilsson et al. (2013) further investigated the muscle activation during DP, by adding horizontal resistance on elite female skiers on a treadmill, and found an increase in mean pole force with increasing speed and horizontal resistance. It is therefore reasonable to theorize that increasing athletes' strength, power and ability to produce more work per cycle would increase power output. However, the changes in technique and physiological responses caused by increased resistance of endurance training have to the best of our knowledge not been investigated. Increasing athletes' ability to produce more work per cycle will increase power output, leading to greater pole force and propulsion. The corresponding changes in muscle activity responses to different workloads of this type may therefore be of interest.

Nilsson et al. (2013) reported a significant increase in mean EMG amplitude in TB, RA and RF with increasing horizontal resistance. Furthermore there seems to be a strong relationship between force development and the EMG signal during specific muscle actions, as there is an increment in the amplitude of the signal with increased loads (Ebben et al. 2009; Gordon et al. 2004; Silva et al. 2008). The findings in the studies by Holmberg et al. (2005) and Nilsson et al. (2013) highlights that the trunk flexors, hip flexors, shoulder extensors and elbow extensors can be considered as prime movers and therefore important to investigate further.

Comparisons between low and high resistance during cyclic work has previously been investigated on elite rowers on a rowing ergometer. Kane et al. (2013) examined the effect low versus high resistance had on rowing economy in elite rowers on a Concept II rowing ergometer. The high resistance tests yielded better gross efficiency during determined workloads and a 3 min all out test. Kane et al. (2013) also reported an increase in freely chosen stroke rate in order maintain the predetermined workloads. Rowing at different resistances on a rowing ergometer would be analogous to altering the pedal crank resistance by selecting different chain combinations in cycling exercises (Hansen et al. 2002). In light of such similarities, cycling at different workloads promotes different muscle coordination patterns, strengthening different muscles (Blake et al. 2012), and sprinters could benefit from training at high workloads to maximize their exposure to the correspondent muscle coordination patterns. In correspondence with Nilsson et al. (2013) and the findings of Kane et al. (2013), one could expect similar findings by altering the resistance when poling on a ski ergometer. Poling at a high resistance could provide a physiological advantage over low resistance during simulated rowing and increase work per cycle when using the high resistance, and would be of interest.

The purpose of this study was to determine what effect different resistances would have on power output, myoelectric activation and physiological responses during a simulated DP on a ski ergometer at different workloads. It was hypothesised that the increased resistance would: 1) improve gross efficiency during submaximal DP at predetermined intensities and 2) have a higher average power output and EMG amplitude during a 3 min all-out test with the high resistance.



## Materials and Methods:

### Subjects:

The project started out with eight male elite cross-country skiers, ended up with a total of six athletes with complete datasets. Physical characteristics of the test subjects are shown in Table 1. The athletes test their  $\text{VO}_{2\text{peak}}$  regularly, and the values shown in the table are the latest testes, which was within 8 months from the experiment.

Table 1: Physical characteristics of the test subjects; age, body height and body mass. Oxygen uptake and training hours were self-reported. Values are mean  $\pm$  SD ( $N = 6$ )

	Test Subjects
Age (year)	21.3 $\pm$ 4.6
Body height (cm)	180.0 $\pm$ 4.5
Body mass (kg)	76.6 $\pm$ 4.3
$\text{VO}_{2\text{peak}}$ [ $\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ ]	70.1 $\pm$ 3.2
Training [ $\text{hours}\cdot\text{year}^{-1}$ ]	573 $\pm$ 105

The participants were informed about the test procedures and signed an informed consent. The study was approved by the Regional Ethics Committee, Trondheim, Norway.

### Experimental overview:

The subjects performed simulated DP on a ski ergometer, with low and high resistance, randomized on 2 separate days to control for learning. The test procedure consisted of three 4 minute submaximal stages and a 3 minute All-out Test. Average power output, Electromyography (EMG), Oxygen Uptake ( $\text{VO}_2$ ), blood lactate concentration (BLa), Pull Length (PL), Cycle Rate (CR), Stroke Time (ST) and Stroke Speed (SS) were recorded during all trials, as well as each subjects perceived Borg's Scale score after each trial.

### Ski Ergometer:

DP was simulated on a modified Concept2 SkiErg (Concept2 Inc., Morrisville, VT, USA). On simulated DP with low resistance, the spiral dampener was set at resistance 1, while with high resistance, the spiral dampener was set at resistance 10. These numbers represent the lowest and highest possible resistances on the ski ergometer, and were selected to ensure a big enough difference between the two modes.

**Kinetics and kinematics:**

To capture CR, PL, ST and SS, seven infrared Oqus cameras (Qualisys AB, Gothenburg, Sweden) were used to capture the displacement of the pulley handles relative to the ergometer. Two passive reflective markers were placed on the right and left handles, and two markers were placed on the ergometer where the ropes entered the ergometer. To ensure that the Oqus coordination system captured high quality data, the system was calibrated before every second test. The data was recorded with Qualisys Track Manager Software (Qualisys AB, Gothenburg, Sweden). The capture frequency was set to 100 Hz and subsequently filtered with a Butterworth low pass filter (8<sup>th</sup> order, 25 Hz, non-recursive).

One cycle was defined as the period between a fully extended pull till the next extended pull. PL was defined as the distance the handle travelled from the beginning of the pull, to full extension. ST and SS were defined as the time to complete one PL and the velocity of the PL (m/s) respectively.

During all testing stages, power was monitored on an integrated Performance Monitor (PM4). Data was then saved and extracted from the integrated LogCard. To validate the data from the PM4, a DST Force Sensor (Noraxon, U.S.A. Inc., Scottsdale, AZ, USA) was installed into the ergometer drive cord within the casing of the ergometer, which measured the subjects pulling force, and was recorded with Qualisys Track Manager Software.

**Physiological measures:**

Oxygen consumption ( $\text{VO}_2$ ) was consecutively measured with open-circuit indirect calorimetry using an Oxycon Pro apparatus (Jaeger GmHB, Hoechberg, Germany). Each day before any tests were conducted, the  $\text{O}_2$  and  $\text{CO}_2$  gas analyzers were calibrated using a high precision gas mixture ( $16.00 \pm 0.04\%$   $\text{O}_2$  and  $5.00 \pm 0.1\%$   $\text{CO}_2$ , Riessner-Gase GmbH & Co, Lichtenfels, Germany). Blood lactate values was obtained from the fingertips of the subjects (20  $\mu\text{l}$  blood sample) and analysed with a Biosen C-Line Sport (EKF-diagnostic GmHB, Barleben, Germany).

### **Electromyography:**

EMG was measured during both submaximal tests and All-out Test. The EMG signals were measured with a Telemyo DTS (Noraxon U.S.A. Inc., Scottsdale, AZ, USA) and recorded using Qualisys Track Manager Software. The sampling frequency was set to 1500 Hz, and RMS was calculated using a 30 ms averaging window width.

The electrodes were pregelled Ag/AgCL dual snap electrodes for surface EMG applications (Figure 8-shaped, adhesive area; 4 cm x 2.2 cm, diameter of each of the two circular conductive areas; 1 cm, inter-electrode distance; 2 cm).

The electrodes were placed parallel to the fibre direction on the muscle belly according to the SENIAM guidelines (Hermens et al. 2000) and were placed on the following muscles; Pectoralis Major (PM), Triceps Brachii (caput longum) (TB), Latissimus Dorsi (LD), Rectus Abdominis (RA), Obliquus Externus Abdominis (OBL), Biceps Femoris (caput longum) (BF), Vastus Lateralis (VL) and Gastrocnemius (caput laterale) (GS). Reference electrodes were placed on Processus Spinosus C7 (C7) and on Tibia (TI). All electrodes were placed on the left side of the subjects' body with exception of PM which was placed on the right side to avoid biological artifact from the heart. Two members of the research team were responsible for the electrode placement, coordinating and ensuring that the electrodes were placed correctly.

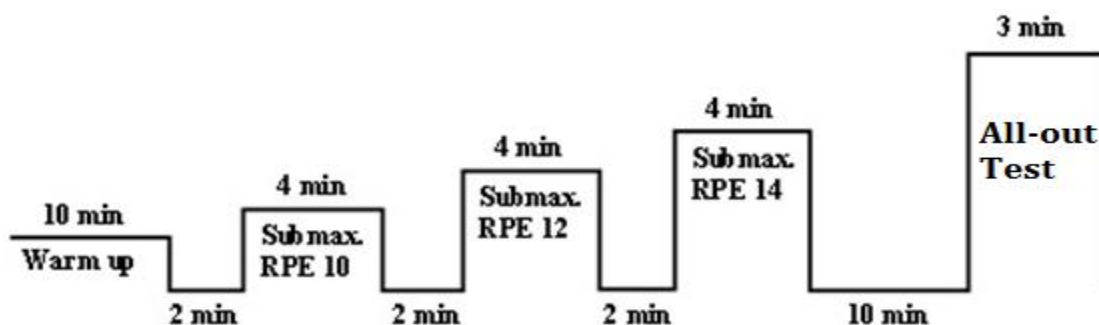
### **Test Protocol:**

When the subjects arrived at the laboratory, it was necessary to place the EMG-electrodes before any initial warm-up procedure. To prepare the area where the electrodes was placed, the skin was shaved, cleaned with conductivity cleaning paste NuPrep (Weaver and Company, Aurora, CO, USA), and alcohol, as in accordance with the SENIAM guidelines. Baseline tests were conducted to ensure proper placements of the electrodes, and before the initial warm-up, baseline values and muscle activation was tested.

Before both tests the subjects performed a standardized 10 min warm-up at low intensity on a treadmill with individual speed and incline. After the general warm-up, the subjects performed specific warm-up where they simulated DP on the ergometer to familiarize with the test movement and the equipment, at a very low intensity.

During the submaximal stages, the subjects were instructed to control their intensities at 10, 12 and 14 on the Borg Scale and their watts as consistently as possible. In order to control the intensity during the submaximal stages, the subjects were ordered to DP on subjective intensities according to Borg's Scale Rate of Perceived Exertion (RPE) (Borg, 1982) which has been shown to be a valid measurement of exercise intensity (Chen, Fan & Moe, 2002). All tests subjects had at least 6 years of endurance training and were used to both the Borg Scale and able to control their intensity according to the scale. Between each submaximal stage, the subjects had 2 minute of rest, in order to sample blood lactate values and acquire the subjects' perceived effort rating on the Borg Scale. Before the 3 minute All-out Test, the subjects were allowed a 10 minute resting period. Figure 1 illustrates the test protocol graphically.

One member of the research team was with the subjects during all tests, in order to give guidelines according to the Borg Scale and motivation during the 3 minute All-out Test.



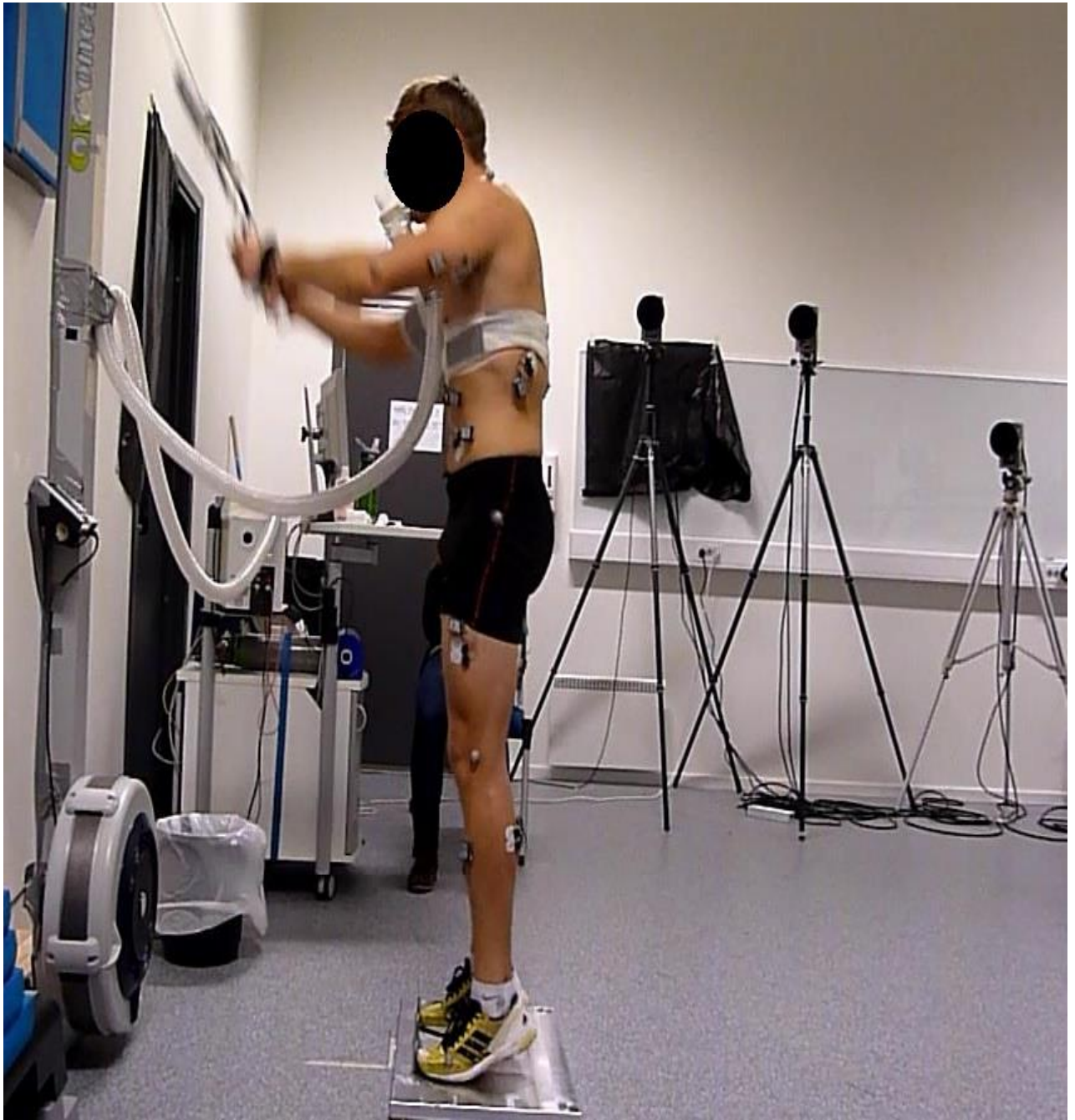
**Figure 1:** Illustration of the test protocol

The 3 minute All-out Test was performed at a high intensity, where the subjects exerted a maximum effort on the ergometer. In order to prevent fatigue however, the subjects paced themselves during the 3 minute bout, but attempted to perform at their maximal ability. One member of the research team consistently motivated and encouraged the test subjects to perform to the best of their abilities, ensuring that the test subjects exerted maximal performance during the All-out Test.

**Analysis:**

Analyses were performed using Matlab, version 8.1.0.604 (The Mathworks inc., USA) and IBM SPSS Statistics, version 21 (IBM Corp., Armonk, NY). Two-way repeated measures ANOVA was employed to analyse the overall effect of resistance (2 levels) and intensities (4 levels) for all variables. Paired Sample T-Tests were employed to assess pairwise differences. GE was defined as work rate divided by metabolic rate, according to Sandbakk et al. (2010). Work rate was extracted from the LogCard, and metabolic rate was calculated as the sum of aerobic and anaerobic metabolic rate. Aerobic metabolic rate was calculated from  $\text{VO}_2$  and  $\text{VCO}_2$ , as a product of  $\text{VO}_2$  and the oxygen energetic equivalent using the corresponding RER-measurements and standard conversion tables (Perronet and Massicotte, 1991).





**Picture 1:** Shows the complete setup where a test subject is performing the simulated DP with all testing equipment.

## Results:

### Physiological measures:

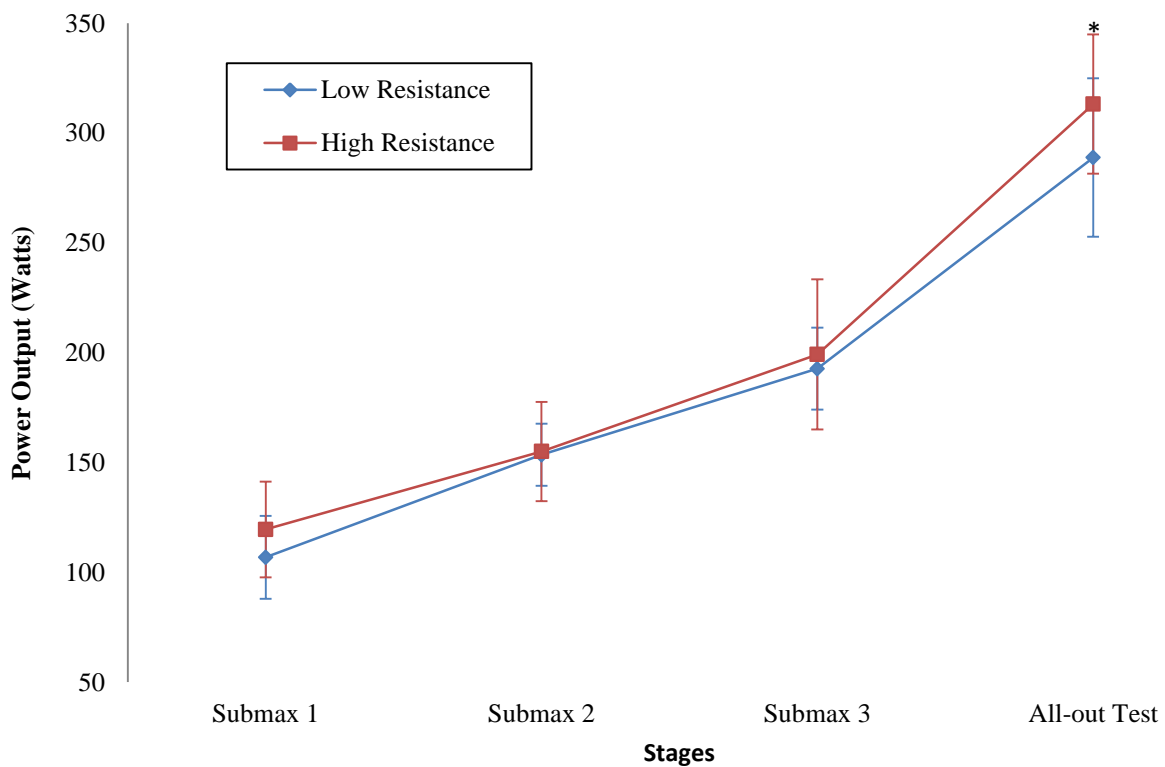
The test subjects showed no differences in BLa,  $\text{VO}_{2\text{peak}}$  or Borg Scale between low and high resistances modes (Table 2).

**Table 2:** Physiological data from the simulated DP tests for low and high resistance respectively. Blood lactate concentration (BLa), oxygen uptake ( $\text{VO}_{2\text{peak}}$ ), and the subjects self-reported exhaustion on Borg Scale Cardiorespiratory Exhaustion and Borg Scale Muscular Exhaustion, values are mean  $\pm$  SD ( $N = 6$ )

	Low Resistance	High Resistance
Submax 1		
Lactate (mmol/l)	$1.6 \pm 0.4$	$1.8 \pm 0.4$
$\text{VO}_{2\text{peak}}$ [ $\text{mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ]	$30.9 \pm 5.8$	$32.9 \pm 4.4$
Borg Scale Cardio (RPE)	$8.9 \pm 1.5$	$9.0 \pm 1.8$
Borg Scale Muscles (RPE)	$8.6 \pm 1.0$	$9.7 \pm 1.2$
Submax 2		
Lactate (mmol/l)	$2.8 \pm 1.0$	$2.8 \pm 0.7$
$\text{VO}_{2\text{peak}}$ [ $\text{mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ]	$41.7 \pm 4.5$	$41.2 \pm 5.6$
Borg Scale Cardio (RPE)	$11.5 \pm 2.0$	$11.3 \pm 1.2$
Borg Scale Muscles (RPE)	$11.8 \pm 1.8$	$12.0 \pm 1.6$
Submax 3		
Lactate (mmol/l)	$4.8 \pm 0.9$	$5.0 \pm 0.8$
$\text{VO}_{2\text{peak}}$ [ $\text{mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ]	$50.5 \pm 5.0$	$51.8 \pm 7.5$
Borg Scale Cardio (RPE)	$14.2 \pm 1.0$	$14.2 \pm 0.8$
Borg Scale Muscles (RPE)	$14.5 \pm 1.8$	$14.0 \pm 0.6$
All-out Test		
Lactate (mmol/l)	$14.4 \pm 2.2$	$15.3 \pm 2.7$
$\text{VO}_{2\text{peak}}$ [ $\text{mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ]	$65.5 \pm 5.0$	$67.4 \pm 5.1$
Borg Scale Cardio (RPE)	$19.2 \pm 0.8$	$19.0 \pm 0.6$
Borg Scale Muscles (RPE)	$19.7 \pm 0.5$	$19.5 \pm 0.5$

### Power measures:

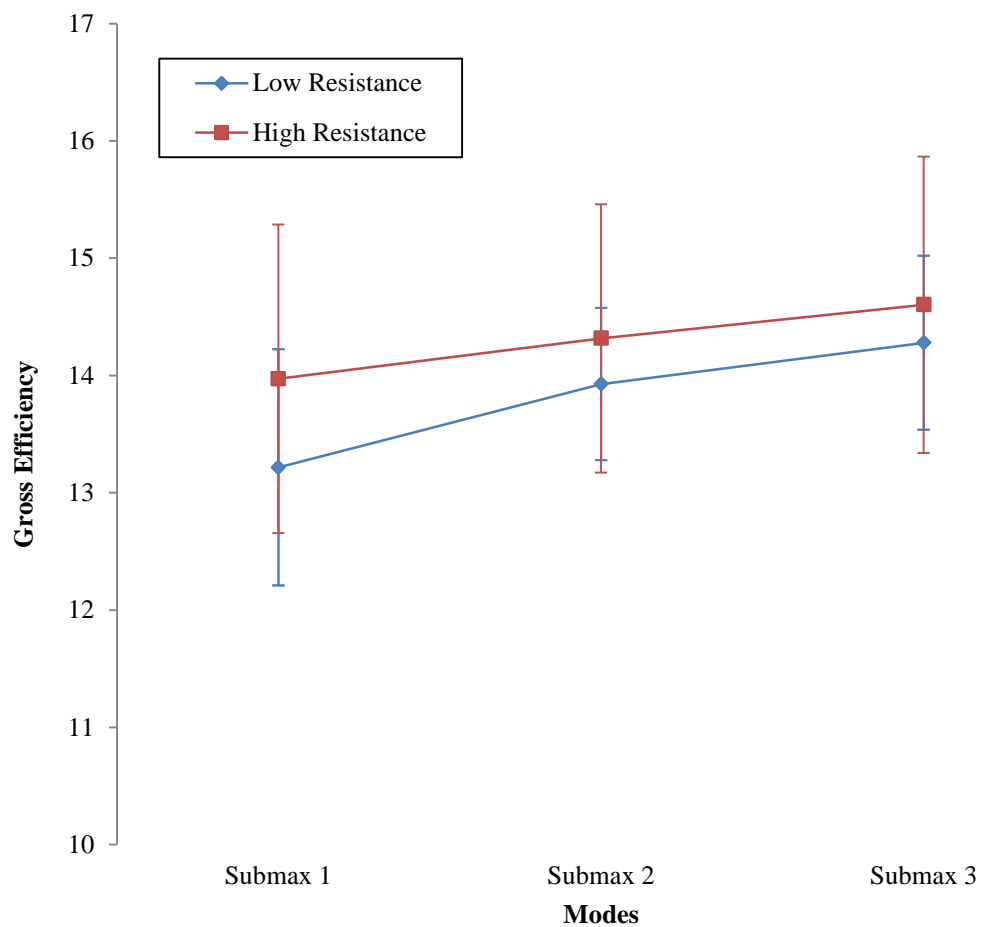
As expected, power output significantly increased with intensity for both low and high resistances ( $P < 0.01$ , Two-way RM ANOVA). There were no overall effect of resistance on power (Two-way RM ANOVA), but the All-out Test showed a significant higher power output with high resistances than with low (paired sample t-test).



**Figure 2:** Mean power output for the simulated DP for low and high resistance at all three submaximal stages and the All-out test. Vertical bars indicate  $\pm$ SD ( $N = 6$ ). Significant differences between resistances are indicated by \*  $P < 0.05$

### Gross Efficiency:

There were no overall effect of resistance on GE ( $P = 0.06$ , 2-Way RM ANOVA, Figure 3) however an effect of intensity were found ( $P < 0.05$ ). There were no pairwise differences between resistances.

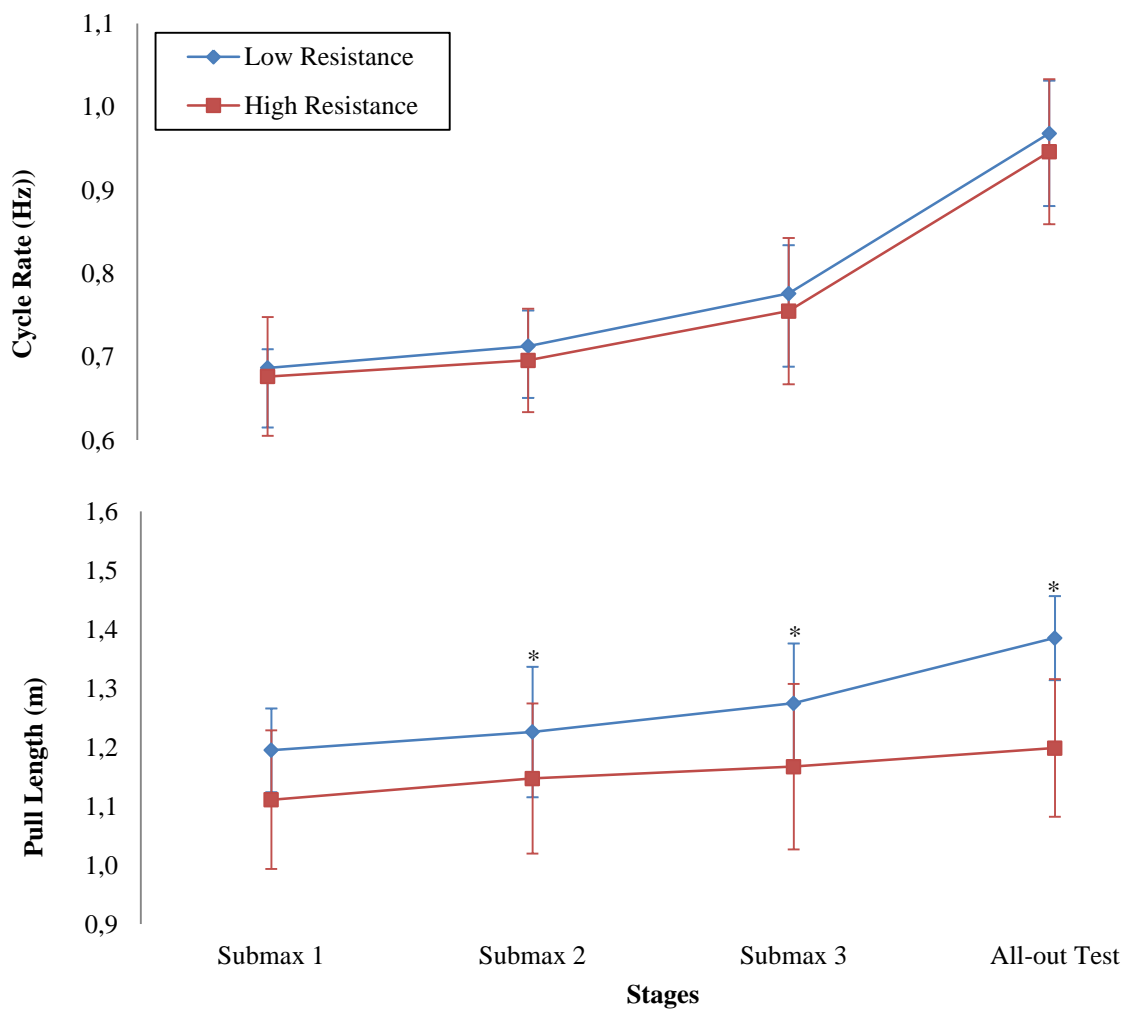


**Figure 3:** GE for low and high resistance across the submaximal stages. Variables are mean GE  $\pm$  SD represented by the error bars ( $N = 6$ ).

### Cycles measurements:

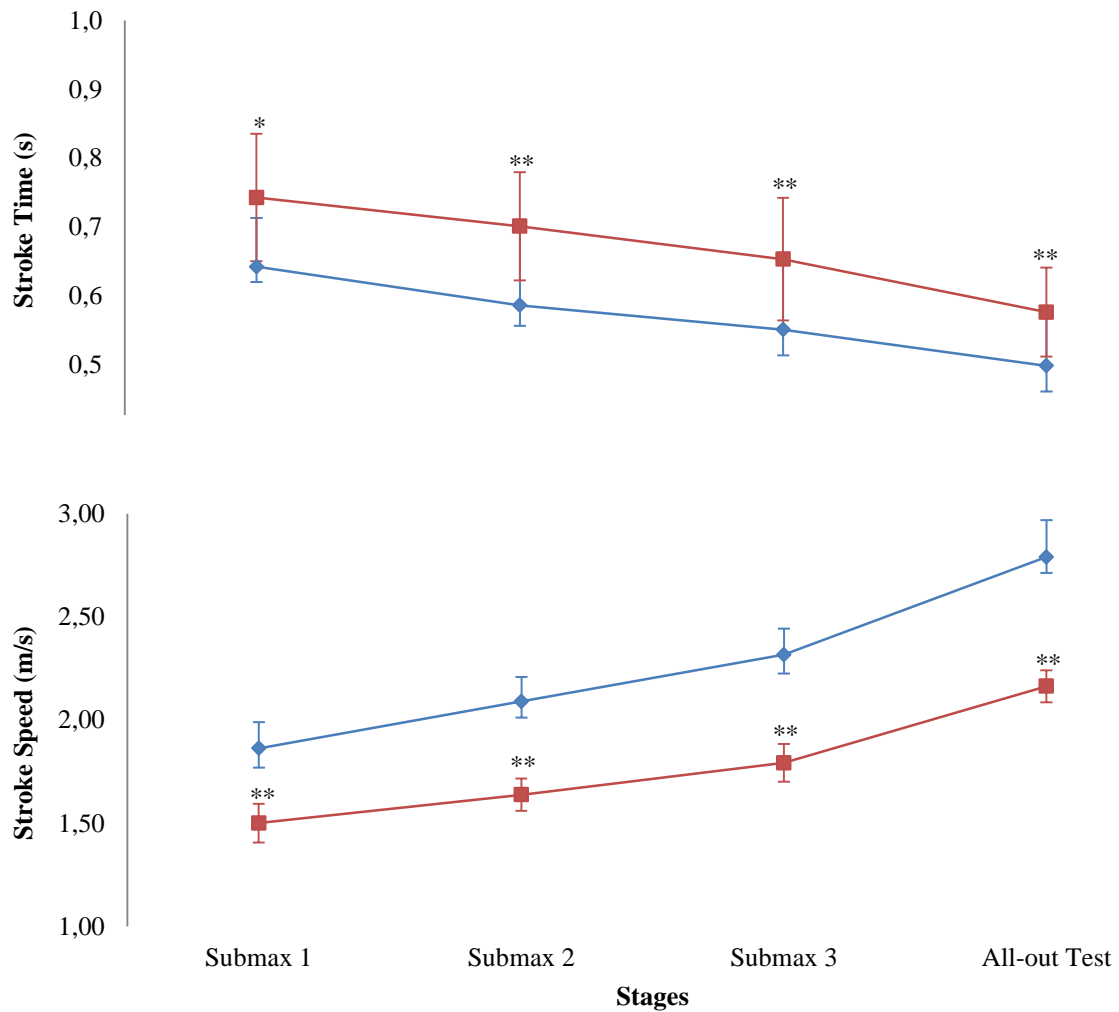
Resistance did not have an overall effect on the CR, but intensity showed a significant effect ( $P < 0.01$ , Two-way RM ANOVA).

PL was affected by both resistance and intensity ( $P < 0.05$ , Two-way RM ANOVA). The subjects produced longer PL at low resistance versus high resistance (Figure 4,  $P < 0.05$ ), with exception of SM1 ( $P = 0.10$ ).



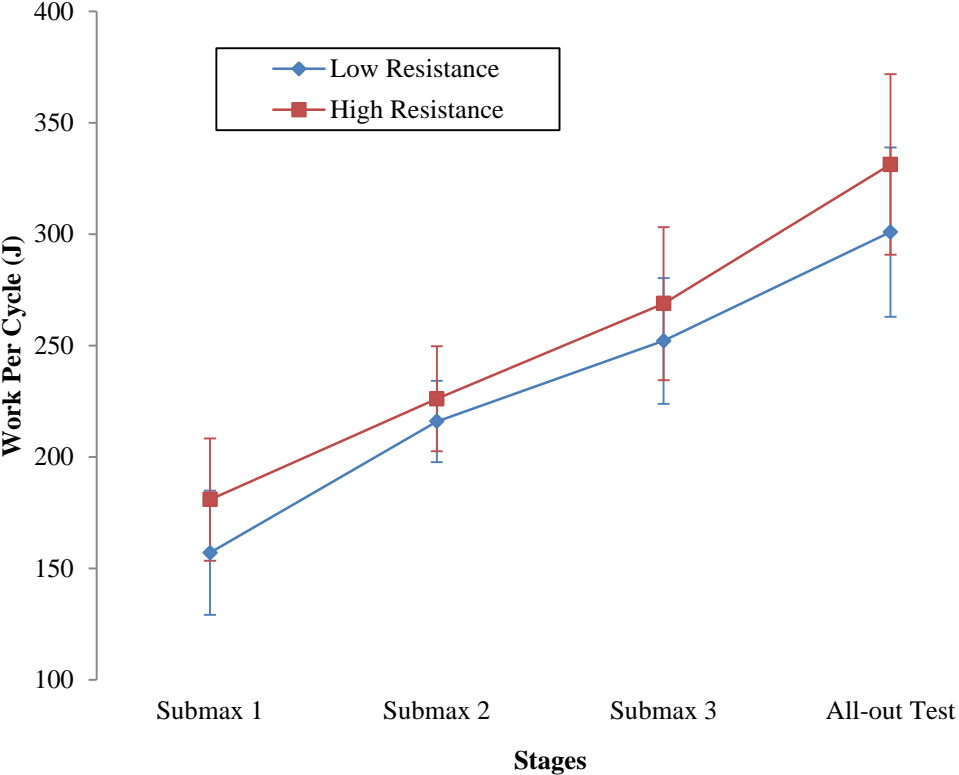
**Figure 4:** Cycle rate and pull length for the simulated DP for low and high resistances. Values are mean cycle rate (Hz) and mean pull length (m). Vertical bars indicate  $\pm$ SD ( $N = 6$ ). Pairwise significant differences between resistances are indicated by \*  $P < 0.05$

In addition, resistance showed an overall effect on ST and SS by significantly higher ( $P < 0.01$ , Two-way RM ANOVA) STs' and lower ( $P < 0.01$ , Two-way RM ANOVA) SSs' respectively at high resistance compared to low resistance (Figure 5).



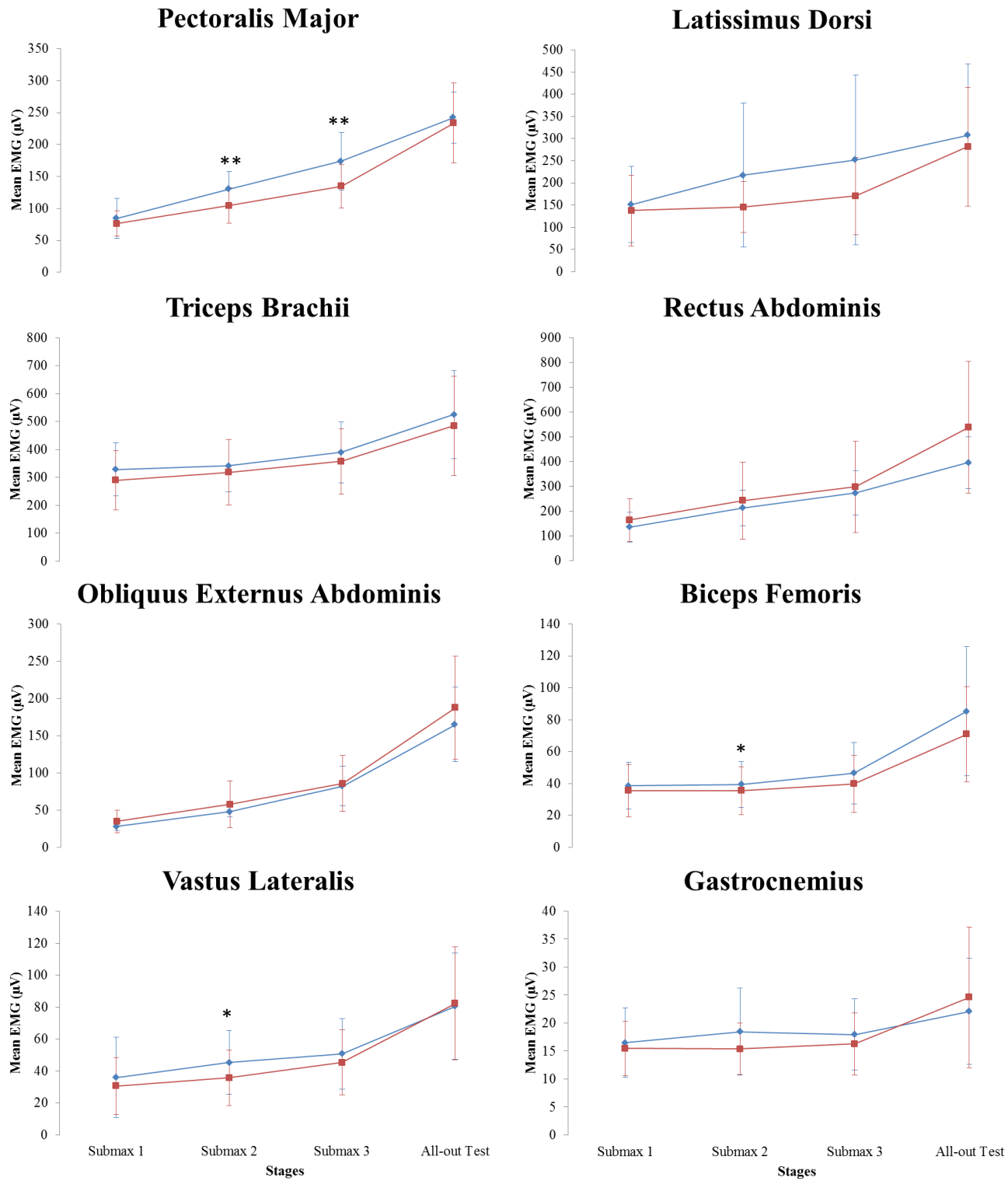
**Figure 5:** Stroke Speed and Stroke Time for the simulated DP for low and high resistances. Values are mean Stroke Speed (m/s) and mean Stroke Time (s). Vertical bars indicate  $\pm$ SD ( $N= 6$ ). Significant differences between resistances are indicated by \*  $P < 0.05$  and \*\*  $P < 0.01$

Resistance showed an overall effect on work per cycle ( $P < 0.05$ , Two-way RM ANOVA) but there were no pairwise differences. Intensity also showed an overall effect on work per cycle ( $P < 0.01$ , Two-way RM ANOVA).



**Figure 6:** Work per cycle for the simulated DP for low and high resistances. Values are mean work per cycle (J). Vertical bars indicate  $\pm$ SD ( $N = 6$ ).

**EMG measurements:** Muscle activation was calculated as mean per cycle, and showed an overall effect of intensity ( $P < 0.05$  for all, Two-way RM ANOVA) but no effect of resistance (Two-way RM ANOVA). TB and RA showed the highest muscle activity patterns, while BF, VL and GS showed the lowest activity. Figure 7 shows pairwise comparison of the measured muscles at both low and high resistance with increasing intensities.



**Figure 7:** Mean EMG for the simulated DP for low and high resistance. Values are mean EMG per cycle ( $\mu\text{V}$ ) ( $N = 6$ ). Significant differences between resistances are indicated by \*  $P < 0.05$  and \*\*  $P < 0.01$



The only pairwise difference between resistance were found in PM (SM2 and SM3,  $P < 0.01$ , paired sample t-test), BF (SM2,  $P < 0.05$ , paired sample t-test) and VL (SM2,  $P < 0.05$ , paired sample t-test). Surprisingly, these differences were significant higher for the low resistance, rather than the hypothesis that they would be higher for the high resistance tests. RA showed an increase in muscle activity during the 3-min All-out Test at high resistance, and the mean value was 35 % higher than the low resistance. However, due to the large standard deviation, the pairwise comparisons were not statistically significant.

## **Discussion:**

This is the first study to the author's knowledge that investigates the effect of resistance on performance during simulated DP in a ski ergometer. Previous studies have had other experimental conditions and this complicates comparisons between studies.

This study compared kinematics, kinetics and EMG during simulated DP in a ski ergometer with two different resistances. The main findings in this study were: (1) CR remained unchanged for both resistances, while high resistance had shorter PL and SS, and a longer ST, (2) High resistance led to a higher power output during the 3 min All-out Test, (3) High resistance had a higher work per cycle, (4) GE was unaffected by resistance, but were affected by intensities, (5) EMG remained unaffected by resistance but were affected by intensities.

No changes in CR were observed between resistances, but ST and SS increased and decreased respectively for high resistance at all stages. PL was also lower, with exception for SM1.

These observed differences are consistent with earlier studies done by Nilsson et al. (2013), where added horizontal resistance while DP on a treadmill increased cycle duration and lead to a relative shorter thrust phase, but no differences in CR. Millet et al. (1998) also reported no differences between CRs' at maximal speed between inclines.

In the present study, resistances did not affect mean power output in the ski ergometer during the submaximal stages. Since the subjects were to DP at submaximal intensities at certain levels of self-perceived exhaustion according to the BORG-scale, the similarities in power output might be affected by the subjects' self-controlled intensity. The All-out Test however, showed a significant increase in mean power output for the resistance mode. This is in accordance with previous literature. The study done by Nilsson et al. (2013) also reported a significant higher mean pole force from the highest to the lowest horizontal resistance. The findings are also in accordance with the findings of Millet et al. (1998), who compared poling forces of DP on a treadmill with two different inclines (2,1 % and 5,1 % uphill), showing a significant increase in both peak force, average peak force and average force over the entire cycle. Both studies show that in order to overcome the added resistance or the steeper grade, an increase in force production is necessary to meet the required power output.

The present study also indicates that in order to overcome the higher resistance provided by the flywheel in the ski ergometer, the subjects needed to generate a higher force, since the CR remained unchanged for both resistances, and that ST increased. The increase in ST is a result of the subjects' requiring a longer duration of the cycle time to produce the required force to overcome the resistance added by the ski ergometer. These findings are supported by earlier studies (Pellegrini et al. 2010), where an increase in incline on the treadmill while performing the diagonal stride on roller skis, resulted in a higher pole force production which was necessary to achieve the required power output to ski at steeper slopes.

Resistance showed an overall effect on work per cycle; however there were no pairwise differences between resistances. There was also an effect of intensity on work per cycle. This is in accordance with earlier findings (Sandbakk et al. 2011), where roller skiing on a treadmill at different inclines lead to a higher work per cycle at the steepest incline. The ability to produce high power output during the pole thrust has been shown to be an important factor for performance in cross-country skiing (Stöggl et al. 2007a,b), and in the present study, necessary to overcome the added resistance provided by the flywheel.

Interestingly, GE only differed across intensities and no effects of resistance were found (even though it was borderline significant at  $P = 0.06$ ). This is contrast to earlier findings done by Sandbakk et al. (2011), where skiing on a treadmill on roller skis at different inclines lead to a higher GE for the steepest incline. However, the present study did not calculate GE during the All-out Test. Calculating the anaerobic metabolic rate is regarded as less accurate than the aerobic and could cause erroneous findings. The lack of difference in GE between resistances may once again be an outcome of the subjects' self-controlled intensity. For further studies, it might be more advantages to allow the subjects to work at specified work rates in watts.

In the present study there was an effect of intensities on muscle activity. This is in accordance with previous studies, where an increase in intensity is accompanied by an increase in muscle activity (Holmberg et al. 2005; Nilsson et al. 2013; Zory et al. 2010). The muscles analysed in this study can be regarded as main contributors in the execution of the DP movement.

however no significant differences were discovered for the high resistance versus the low resistance. In the study of Nilsson et al (2013), there was a significant higher muscle activity in the measured muscles at the highest versus the lowest horizontal resistance. Force development and EMG signal has previous been shown to have a strong relationship, as the amplitude increases with the loads (Ebben et al. 2009; Gordon et al. 2004; Silva et al. 2008)

and as shown by Nilsson (2013). The findings in the present study show no such effects of resistance on muscle activity in the measured muscles with the increased resistance. Rather there were some muscles that showed a significant increase in mean EMG activity at low resistance versus high resistance (PM, BF and VL). Interestingly, RA showed a big leap in activity during the 3 min All-out Test at high resistance, however, due to the large standard deviation, the measured activity was not significantly higher for the high resistance versus the low resistance.

A possible explanation for these findings might be caused by changes in the subjects' technique between the two resistances. Even though no significant differences were found for RA, the average mean for the All-out Test was 35 % higher at the high resistances versus the low resistance. This might indicate a shift in technical execution. A more thorough qualitative analysis of the technique performed by the subjects could answer the differences in muscle activation. Additionally, investigating the timing and synchronization of the muscle sequencing patterns could be of great interest for further studies with similar research questions. However that is outside the scope of this paper.

#### **Limitations of the study:**

The number of subjects was reduced from eight to six in the course of the project. Inclusion of more subjects to the study could have been advantageous to discover significant differences between the resistances.

#### **Concluding remarks:**

The purpose of this study was to investigate the effect different resistances would have on simulated DP in a ski ergometer. According to the hypothesis, the subjects were able to produce higher power output during the 3 min All-out Test and a higher work per cycle across all stages at high resistance. GE however did not increase as a result of high resistance. CR did not differ at the two resistances, but PL and SS were shorter and ST was longer at high resistance. It is feasible to assume that these changes occurred due to the required increase in force to overcome the higher resistance in the ski ergometer. The increases in power output and work per cycle could not be explained by increased muscle activity and further investigations as to why these changes occur are required.

## References:

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