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ROLLER SKIING: PHYSIOLOGICAL RESPONSES AND COMPARISON WITH RUNNING AT SAME INTENSITY IN CROSS-COUNTRY SKIERS

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Abstract
The purpose of our investigation was to compare some physiological, metabolic and respiratory responses in roller ski and submaximal running exercise at preferred levels of exertion.
Four males and six females junior cross-country ski racers performed 30 min submaximal roller skiing and running (75% HR max) at least 2 days between bouts for any given subject. Heart rate (HR), Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), tidal volume (V_T), oxygen pulse (O_2 pulse), minute ventilation (V_E), respiratory exchange ratio (RER) and metabolic equivalent (MET) were monitored continuously using a portable, breath by breath spirometry system. Blood samples were obtained from fingertip at baseline, at the end and five minutes after exercise and analyzed for whole blood lactate concentration. The same test protocol was used for all two exercise modes.
HR, $\dot{V}O_2$, $\dot{V}CO_2$, O_2 pulse and MET were significantly higher in running than roller skiing only in the first three minutes of exercise sessions.
A significantly higher $\dot{V}O_2$ was observed during running exercise than roller skiing, but there were no differences in lactic acid levels, minute ventilation and RER. Tidal volume also showed a significant increase in roller ski exercise after 15 minutes compared to running.
We conclude that roller ski and running are both equally valuable for training endurance ability in cross-country skiers. Coaches and athletes should be aware that roller ski and running elicit similar blood lactate concentration and heart rate at a given exercise intensity.
Future studies should compare the cardiovascular training effects of running and roller ski exercise in individuals of varying levels of fitness and skiing ability.

Key Words: sub maximal exercise, $\dot{V}O_2$ max, XC Skiing

Introduction

Which activities do successful cross-country (XC) ski racers actually do for conditioning? Although training varies considerably among the best elite athletes, it is possible to generalize to some degree (P. Petersen et al. 1999). Skiing just as the concept of specificity explains, the best training for the ski racing is skiing. The best skiers practice on glaciers in summer (N.V. Mahood et al. 2001). But only skiing is not enough for conditioning and also is not possible. The other several training methods are as follows, ranked in order of specificity for nordic ski racing; roller skiing, ice skating and in line skating, hill work with ski poles, rowing, hiking, running, cycling and others include orienteering, rock climbing, kayaking, triathlons, swimming, tennis and soccer (P. Gervais, C. Wronko 1988; A.J. Larson 2006; P. Petersen et al. 1999).

The single physiological variable that most clearly distinguishes the champion cross-country skier from the average person or even the highly trained but less successful skier is the maximal oxygen consumption (S. Seiler 1996). In the unforgiving world of XC racing, there seems to be no substitute for a BIG ENGINE (U. Bergh 1982; F. Ingjer 1991). This capacity requires both genetics and also hard training (K.W. Rundell, D.W. Bacharach 1995).

Ingjer demonstrated that the average $\dot{V}O_2$ max of world class skiers was significantly greater than that of less successful skiers only when it was divided by lean body mass, not when it was divided by simple body mass. One thing is clear, the teams which have the greater success are those which have skiers with the highest maximal oxygen consumption (F. Ingjer 1991).

Training may be regarded as a tool that when used correctly elicits specific physiological responses. Each stage of the training plan, the amount and type of exercise one does will determine how fit and race ready one will become. The physiological effects of each training intensity will dictate the amount of training component scheduled during a given training cycle (M. Boyle 2004). Every level of cross-country skiers must include a certain amount of endurance exercise in the program. Over distance training is an important component for developing and maintaining aerobic capacity and maximal oxygen consumption (R. Sleamaker, R. Browning 1996). Low intensity overdistance training sessions are most effective if

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the intensity is between 55 and 65 percent of $\dot{V}O_2$ max.

The more oxygen can be delivered to the working muscles, the greater the energy supply, and the faster the body can ski over distance (E. Cetin, I. Yarım 2006; J. Newton, J. Henderson 1998).

Running is a simple training technique, which has been used in one form or another throughout the history of sports. Over the years, a number of Olympic, professional and amateur athletes have used running to improve their performances. Athletes in almost all sports use running to improve especially their aerobic capacity (G.T. Moran, G. McGlynn 1997). Running activities such as distance exercise are very effective in increasing the ability of cardio respiratory system to supply oxygen to the working muscles. Cross-country skiers often use distance running during the whole season to maintain aerobic performance (G.T. Moran, G. McGlynn 1997; R. Sleamaker, R. Browning 1996). Running can provide excellent aerobic work but it does not account for upper body fitness. The endurance capacity of the upper body has always been important for the skier. One of the areas where most endurance athletes are weak is upper body endurance and power. Among elite skiers, an interesting pattern occurs during the season. Whole body maximal oxygen consumptionpeaks very early in the seasonal build-up. However, performance peak during the season seems to correspond to the peaking of upper-body endurance capacity**,** measured as upper body peak $\dot{V}O_2$ (U. Bergh 1987).

The next best method of practising cross-country skiing during the summer is roller skiing. The summer and fall are critical training months for cross-country skiers. Roller skiing is a must for those who are serious about progress. The best juniors, elite and master skiers are spending 25-50% of their training time on roller ski (M.D. Hoffman et al. 1992). This training method effects especially on improving the cardiovascular and neuromuscular functions required for cross-country skier (F. Wöllzenmüller 1982).

The purpose of this investigation was to compare some physiological, metabolic and respiratory responses to roller ski and running exercise at preferred submaximal levels of exertion. Four males and six females elite cross-country ski racers performed 30 min submaximal roller ski and running exercises.

METHODS

Experimental Approach to the Problem

This study used a repeated measures design to examine the effects of different exercise modes, namely 30 min submaximal roller ski and running exercise, on oxygen uptake, heart rate and blood lactate.

Ten subjects (4 women and 6 men) were tested on 2 occasions using a different mode of exercise for each test: running and roller skiing. A combined-sex group was used because the exercise modes tested are common training modes for both male and female cross-country skiers. There are no known gender specific differences in the submaximal physiological responses to these modes of exercise. Consequently, the data for men and women were pooled to provide a total sample size of 10 test subjects.

The test sequence was randomly assigned to each subject over 1-week period. Tests were conducted in the post competition season, during the recovery phase of the training cycle. Usual training prior to testing included daily on-snow skiing, running and weight training; training had been ceased one week prior to testing. All subjects were comfortable with roller skiing and running on it. All exercise modes followed the same protocol.

Subjects

Ten cross-country junior ski racers, 4 women and 6 men volunteered to be tested. Prior to testing, each subject provided his or her written consent to participate in the study. Subjects were well-trained, regional or international level competitors. Subjects had at least 6 years of competitive experience in cross-country skiing and roller skiing.

Procedures

Height and weight were measured on the day of the first test, prior to testing, using a stadiometer and a calibrated scale. Subject characteristics can be found in Table 1. Subjects were randomly assigned to a testing sequence that included either a 30 minute submaximal running or roller ski exercise. The testing sequence was randomized for all subjects to reduce any training or learning effect. All tests were administered during one week period with at least 2 days between bouts for any given subject. Due to scheduling constraints, tests were scheduled throughout the day between 9:00 AM and 13:00 PM in 20–22 ^{0}C.Subjects were instructed not to exercise or train on the day of testing and to maintain their usual diet.

Subjects used the same pair of Eagle Skate, ratcheted roller skis (100 mm) for the roller ski exercise. Subjects used their own boots, poles, and helmet, which they commonly used in training. Skate poles generally reached the subject's upper lip.

All tests were performed with the same method; it was a 30 minutes sub-maximal field roller skiing and running test. Roller skiing exercise was run on 1 km flat asphalt course and 400 m running on standard track in a field stadium. Athletes had rested at least two days between the roller ski and running exercises. Exercise intensity was determined as 75 % of the individual's heart rate according to Carvonen method. Subjects performed a warm-up, using the mode of exercise to be tested, for 15 minutes.

Accutrend Portable Lactate analyzer and BM Lactatestrips (Boehringer, Manheim, Germany) were used to determine the lactic acid levels. The blood samples were obtained at fingertip at baseline (a), at the end of 30th (b) and 35th minutes (c), strip was analyzed for whole blood lactate concentration. The same sampling protocol was used for both two exercise modes

Gas analysis during the submaximal exercises was completed with a portable breath-by-breath gas exchange measurement system (V_{max} ST 1.0, Cortex Biophysik GMBH, Leipzig, Germany). This system was calibrated prior to each test under ambient conditions for volume and gas concentrations. TheV_{max} ST 1.0 system is lightweight(650 g), with the main sample unit attached to the chest and a battery pack on the back of the harness. A face mask is used to measure direct airflow through the turbine and to permit sampling of expired air. The design permitted high level performance with no serious interference with normal ski technique. We used the unit in stand-alone data recording mode, but it could have also been used with telemetry if the testing would have been conducted closer to the base. Heart rate (HR), Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), pulmonary ventilation (V'E), energy output (Q), tidal volume (VT), inspiratory volume (IV), oxygen pulse (O_2 pulse), O_2 intake volume (O_2 intake), minute ventilation (V_E), respiratory exchange ratio (RER) and metabolic equivalent (MET) were recorded.Heart rates were continuously measured by a Vantage XL Polar Heart Rate Monitor (Polar OY, Finland) telemetry device and averaged over the 15 seconds of each stage during each exercise.

Statistics

Statistical analyses were performed with SPSS (version 10); Means and standard deviations (SD) are given as descriptive statistics. A repeated measurement ANOVA was used for evaluation within groups and between groups' differences by independent sample t-test; p<0,05 was considered to be statistically significant.

RESULTS

Oxygen consumption values and metabolic parameters are given in Table 2., blood lactate values in Figure 1. and $\dot{V}O_2$, $\dot{V}CO_2$ values for running and roller skiing exercises (0,1,3,5,10,15,20,30,35 min) are shown in Figure 2.

There is a significant difference between heart rate parameters at 1th, 3rd and 35th minute and O_2 intake and Q differ at 1th minute of exercise ($p<0.05$) between running and roller skiing exercises.

Tidal volume at 15th, 20th and 25th minute of exercise and specific V_E at only 35th minute of exercise was significantly different ($p<0.05$) among exercise modes.

There is a significant difference between running and roller skiing exercises in V'E, $\dot{V}O_2$, $\dot{V}CO_2$, METand O_2 pulse at 1st and 35th minutes ($p<0.05$).

There is no significant difference between running and roller skiing exercises at inspiratory volume and respiratory exchange ratio ($p>0.05$).

There was a significant difference in terms of LA levels in both groups when compared pre and post exercises ($p<0.001$); but there was no significant difference between blood lactate concentrations between exercise modes (Figure 1).

However looking at the differences between LA levels as percentages, in running exercise between the first and second measurement there is a 292,59 % increase, between the second and third measurement, there is a 15,49% decrease. In roller skiing between the first and second measurement, there is a 268,25% increase; between second and third measurement, there is a 17,95% decrease.

Cross-country athletes make 6765,00 ± 669,179 m in running and 9018,25 ± 625,327 m in roller skiing during 30 minutes submaximal exercises.

DISCUSSIONS

The purpose of our investigation was to determine if among different modes of exercise, there is a significant difference in heart rate, lactic acid concentration, some respiratory and metabolic parameters, or if there is a significant difference in exercise stages. It was hypothesized that there would be a significant difference in heart rate when comparing roller ski exercise with running exercise. Athletes and coaches in almost all sports use running to improve especially their aerobic endurance (R. Sleamaker, R. Browning 1996). Although how roller ski exercise affects $\dot{V}O_2$max is literally unknown. So the second hypothesis was submaximal roller ski exercises could develop endurance capacity as running exercise.

Results of our study partially support the hypothesis that only the first three minutes of both exercise modes elicit different outcomes in terms of the parameters measured. Although between 3-30 minutes no significant difference has been found, there was a significant difference in heart rate between 0-3 minutes of exercise modes. As compared with running this lower heart rate for roller ski was associated with exercise intensity. The reason of this results seems that running exercise mode has higher working intensity in first 3 minutes than roller skiing (M. Boyle 2004; M.L. Foss et al. 1998). Also roller skiing exercise's total movement pattern has two different parts; push and glide (as shown in Table 2. heart rate support this result) (P. Gervais, C. Wronko 1988).

Snyder examined the physiological responses of nine trained volunteers (2 males, 7 females) during in-line skating and compared it with running and cycling. Results show that heart rate response during in-line skating was lower than running and cycling (A.C. Snyder et al. 1993).

Melanson et al. compared the physiological demands of in-line skating and running at self-selected exercise intensities. Ten males and ten females performed 15 minutes of in-line skating or running on two separate days, while HR and $\dot{V}O_2$ were measured continuously. Melanson et al. found no differences in V_E, HR, or ratings of perceived exertion (RPE) between in-line skating and running (E.L. Melanson et al. 1996). Our results are similar to Melanson's results but contrary to Synder's.

Furthermore, running exercise elicited insignificantly higher mean blood lactate concentrations for every exercise stage compared with roller skiing. These findings could be important in determining appropriate heart rate-based intensity zones for roller ski training. The relationship between blood lactate concentration and heart rate is important in the prescription of intensity-based training zones for cross-country skiers and other endurance athletes to optimize training and prevent over-reaching (P. Bourdon 2000).

Martinez had performed 3 maximal exercise tests with nine athletes (6 males and 3 females) from the National Roller Skiing team. In contrast to our result, maximal blood lactate was significantly lower in running compared to cycling and roller skating (M.L. Martinez et al. 1993). These differences depend on exercise intensity as in this study submaximal exercise intensity was used.

After 5 minutes of exercise lactic acid removal was insignificantly higher in roller ski than running. Exercise specificity, i.e. upper body involvement for roller skiing, as well as protocol characteristics, particularly exercise modes, could explain this discrepancy. Our results stress the importance of the upper body component in cross-country skiing and that the aerobic energy cost discriminates between skiers of different standard (M. Gregoire et al. 2003).

The primary removal mechanism for lactate is oxidative metabolism (G.A. Brooks 1986). This can take place in lactate-producing cells, or the lactate can be shuttled to other cells and oxidized as an energy-yielding substrate (G.A. Brooks 1986). This potential lactate removal pathway may be enhanced by combined upper- and lower-body exercise such as roller skiing. By contrast, in running exercise, the legs have a lower metabolic output and would not need to oxidize lactate for additional ATP synthesis. This would result in a net increase in blood lactate accumulation.

These data are often used for prescription of heart rate-based exercise intensities and zones regardless of exercise mode that is used in training sessions. Because running utilizes only the lower body and cross-country skiing has a large upper-body component, several studies suggest that discipline-specific tests may be more appropriate for the evaluation of cross-country skiers and prescription of exercise intensities (E. Mygind et al. 1991; K.W. Rundell 1995, 1996).

The main finding of our investigation is similar $\dot{V}O_2$ max values during running and roller skiing were attained by elite cross-country skiers who were active and trained in fitness status.While intensity of exercise in both exercise modes was 70 %, increase in tidal volume of both two exercise types was not significantly different until 15^{th} minute. Augmentation inalveolar ventilation during exercise results from an increase in both the rate and depth of breathing. The volume of gas moved during each respiratory cycle is the tidal volume (P.O. Åstrand, K. Rodahl 1987). There is an increased dependence on breathing frequency versus Tidal Volume as exercise intensity increases. In submaximal exercise, well trained athletes maintain alveoler ventilation by increasing tidal volume with only a small increase in breathing rate (W.D. McArdle et al. 1991). However, tidal volume of running exercise was significantly lower than roller ski exercise between 15^{th} and 20^{th} minutes ($p<0,05$).The loss of tidal volume reserve, therefore, serves as the primary mechanism for the overall loss of pulmonary reserve with fatigue. The primary factor for the decreased dependence on tidal volume during exercise of increasing intensity is the structural disintegration that comes from a gradual loss of lung support structure elasticity (S.P. Brown et al. 2006).

The portable breath-by-breath monitoring system provided an excellent opportunity to monitor $\dot{V}O_2$ peak in athletes during roller ski and running exercise. Except after the first minute of exercise no significant differences ($p>005$) were found in $\dot{V}O_2$ max (ml/kg/min), Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), pulmonary ventilation (V_E) and metabolic equivalent (MET) between roller ski and running exercises. Running and roller ski did not differ significantly from each other with respect to this increase in $\dot{V}O_2$ max; nor did they demonstrate significant changes in respiratory exchange ratio (RER) at $\dot{V}O_2$ max between submaximal exercise periods.

This phenomenon could be explained that during mild, steady-state exercise, ventilation accurately reflects the rate of energy metabolism.

Ventilation parallels oxygen uptake. The ratio of air ventilated to oxygen consumed is the ventilatory equivalent of oxygen ($V_E/\dot{V}O_2$) (J.H. Wilmore, D.L. Costill 1994).

Since oxygen uptake is the product of systemic blood flow (cardiac output) and systemic oxygen extraction (arteriovenous oxygen difference), changes in $\dot{V}O_2max$ are due to changes in maximal systolic volume, maximal HR, or maximal arteriovenous oxygen difference ((a-v)O_2 difference) (S.K.Powers, E.T. Howley 2001).

For example, in a study by Koepp significant difference was also present for $\dot{V}CO_2$ ($L \cdot min^{-1}$) between running and skating; this could be due to the fact that $\dot{V}CO_2$ rises linearly with $\dot{V}O_2$ (oxygen consumption) but at a faster rate. Therefore, as $\dot{V}O_2$ increases, $\dot{V}CO_2$increases in excess (K.K. Koepp 2005).

Melanson found no differences in V_E, HR, or RPE between in-line skating and running (E.L. Melanson et al. 1996). However, $\dot{V}O_2$ and EE were significantly higher during running (Martinez et al. 1993; Melanson et al. 1996). Our study shows similar results whereas there were no significant differences in V_E, HR, V_T, and O_2 pulse between running and treadmill skating, but a higher $\dot{V}O_2$($ml \cdot kg^{-1} \cdot min^{-1}$) and $\dot{V}CO_2$($L \cdot min^{-1}$) was seen during running than treadmill skating. Again, this could be due to the position of the body while skating and the compromised HR, SV, and (a-v) O_2 difference caused by a decrease in muscle blood flow.

Our study shows similar results that there were no significant differences in V_E, HR, VT, and O_2 pulse between running and roller skiing.

PRACTICAL APPLICATIONS

Cross-country skiing is mainly an aerobic sport, our results stress the importance of the upper body component in cross-country skiing and that the aerobic energy cost discriminates between skiers of different standards.

Our study revealed that the roller ski produced similar maximal physiological values compared to running during this experiment protocol.Roller ski can be recommended as a beneficial training and recovery exercise method for cross-country skiers. Roller ski showed similar physiological values with running. It was concluded that these skiers, were well-trained in both running and roller ski. Similar improvements in $\dot{V}O_2$ max could be achieved with running and roller ski programs that are equivalent in training volume and intensity. A potential advantage of roller ski is that aerobic training intensities can be obtained at competitive velocities. These results show that roller ski can be regarded as an alternative to snow skiing for off-seasonal training in Nordic disciplines.

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Tables and Figures

TABLE 1.

Physical characteristics of the subjects (mean ± SD)

Height (cm)	**Weight** (kg)	**Age** (years)
165.63±5.66	56.33 ±7.1	16.87 ±1.87

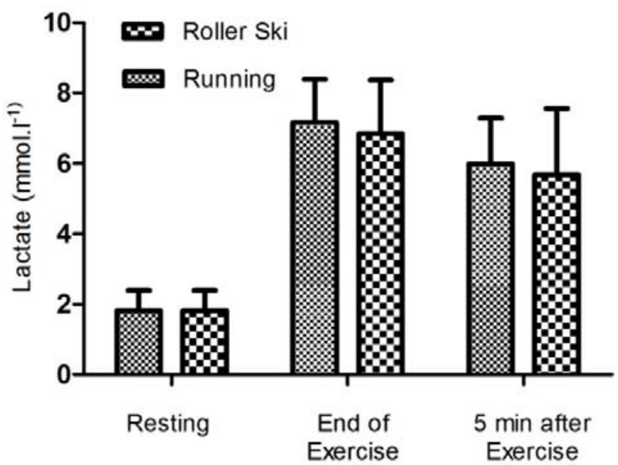

FIGURE 1. Lactate levels in running and roller skiing at resting, end of exercise and after 5 minutes of exercise

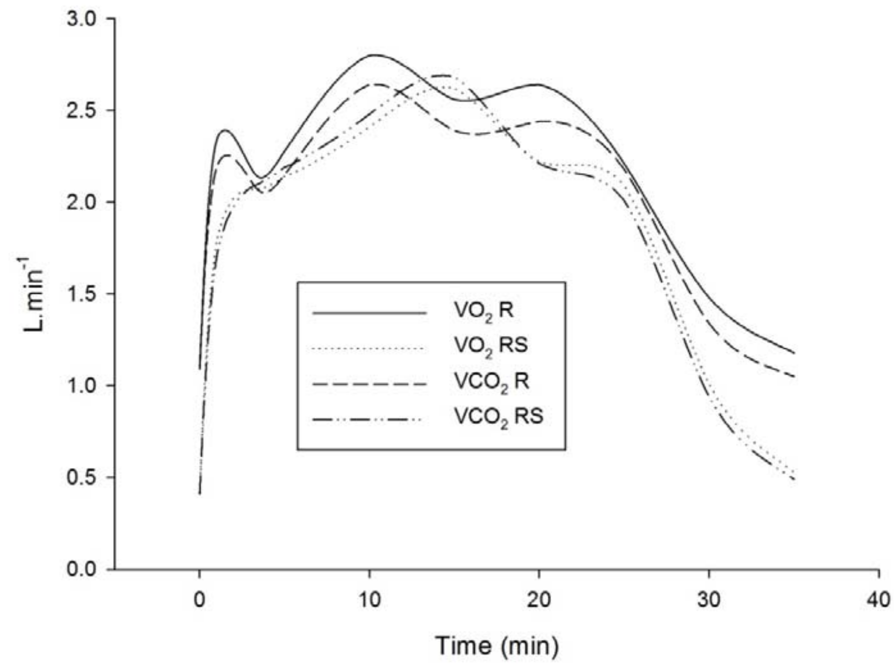

FIGURE 2. Oxygen consumption and Carbondioxide production in running (R) and roller skiing (RS)

TABLE 2. Measurement results and evaluation of metabolic changes in running and roller skiing exercises.
* p<0,05; ** p<0,01 NS=None Significant

Parameters	Exercise mode	0 min	1 min	3 min	5 min	10 min	15 min	20 min	25 min	30 min	35 min
HR (beats/min)	Run	116,33±30,80	164,66±7,79	174,11±7,00	178,88±9,82	187,33±8,71	187,00±6,67	184,22±6,83	187,22±6,20	186,22±6,11	157,00±25,76
	Rollerski	108,11±18,58	147,33±31,16	166,88±17,85	177,55±9,38	182,66±8,51	184,33±8,78	182,33±9,32	185,22±9,17	186,77±8,52	128,00±19,04
	Significance	NS	*	*	NS	NS	NS	NS	NS	NS	*
V_T (L/breath)	Run	0,69±0,35	1,67±0,70	1,64±0,42	1,67±0,38	1,56±0,31	1,46±0,22	1,39±0,26	1,37±0,36	1,33±0,31	0,81±0,26
	Rollerski	0,51±0,23	1,17±0,66	1,45±0,40	1,64±0,36	1,60±0,32	1,58±0,44	1,44±0,45	1,45±0,30	1,35±0,28	0,77±0,13
	Significance	NS	NS	NS	NS	NS	*	*	*	NS	NS
V_E (L/min)	Run	21,71±9,90	66,48±26,48	76,28±24,94	78,82±25,45	85,97±22,42	80,88±18,64	81,87±17,35	80,33±19,09	83,35±18,00	35,91±10,01
	Rollerski	14,96±8,93	54,79±42,88	75,90±31,52	81,67±25,08	82,93±27,52	91,68±26,68	78,84±25,61	75,06±24,52	82,23±27,39	18,22±6,92
	Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
RER	Run	1,02±0,22	0,93±0,10	0,86±0,33	0,84±0,31	0,94±0,05	0,93±0,06	0,93±0,08	0,94±0,60	0,92±0,71	0,91±0,12
	Rollerski	0,86±0,35	0,93±0,07	0,87±0,33	0,90±0,34	1,02±0,05	1,01±0,06	0,99±0,10	0,96±0,05	0,92±0,08	0,90±0,10
	Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$\dot{V}O_2$ ($L.min^{-1}$)	Run	1,0±1,1	2,34±0,95	,19±1,15	2,28±1,23	2,80±0,92	2,56±0,77	2,64±0,86	2,21±0,90	1,48±0,98	1,18±0,48
	Rollerski	0,4±0,3	1,78±0,41	,07±1,21	2,14±1,10	2,41±0,70	2,62±0,92	2,22±0,68	2,09±057	1,01±0,67	0,53±0,26
	Significance	NS	*	NS	NS	NS	NS	NS	NS	NS	**
$\dot{V}CO_2$ ($L.min^{-1}$)	Run	1,11±1,14	2,19±0,93	2,12±1,20	2,15±1,15	2,64±0,88	2,39±0,67	2,44±0,74	2,18±0,48	1,34±0,84	1,05±0,37
	Rollerski	0,41±0,30	1,70±0,39	2,08±1,29	2,19±1,15	2,48±0,80	2,68±0,99	2,21±0,72	2,01±0,37	0,94±0,97	0,49±0,23
	Significance	NS	*	NS	NS	NS	NS	NS	NS	NS	**
O_2 Pulse	Run	4,59±6,79	14,13±5,58	12,55±6,40	12,84±6,81	15,00±4,93	13,79±4,48	14,38±4,90	13,35±4,88	14,09±4,59	7,43±2,71
	Rollerski	3,40±1,81	7,07±3,87	12,48±6,84	12,54±6,32	13,66±3,40	14,95±4,64	12,50±3,17	13,20±3,23	13,68±4,96	4,41±2,81
	Significance	NS	**	NS	NS	NS	NS	NS	NS	NS	*
MET	Run	2,98±0,43	12,35±3,60	13,40±3,11	14,04±3,49	14,92±2,97	13,89±3,43	14,09±3,14	13,24±3,17	14,03±3,45	6,70±3,03
	Rollerski	2,14±1,45	9,17±6,50	12,17±3,65	12,57±2,30	12,75±2,42	13,75±3,46	11,84±3,19	12,63±2,29	13,02±3,22	2,77±1,49
	Significance	NS	*	NS	NS	NS	NS	NS	NS	NS	**