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ORIGINAL ARTICLE

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Effects of 20-s and 180-s double poling interval training in cross-country skiers

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Abstract The purpose of this study was to investigate the effect of upper body 20-s or 180-s interval training, using a double poling ergometer, on upper body power output and selected physiological and biomechanical parameters in cross-country skiers. Twenty (12 male, 8 female) well-trained cross-country skiers took part. Two intervention groups, a 20-s interval training group (IT20; $n = 6$) and a 180-s interval training group (IT180; $n = 7$), underwent training three times a week for 6 weeks on a double poling ergometer. A third group served as a control (CON; $n = 7$) and followed the same training program as the IT20 and IT180 groups without the double poling ergometer interval training. The IT20 and IT180 groups significantly ($P < 0.05$) increased both peak and mean power in a 30-s test and mean power in a 6-min test after double poling training. There was a significant improvement in work efficiency in both IT20 and IT180 ($P < 0.05$) and, in IT180, a significant reduction ($P < 0.05$) in blood lactate concentration at given sub-maximal workloads. $\dot{V}O_{2peak}$ increased significantly during double poling in IT180 ($P < 0.05$) only. $\dot{V}O_{2max}$ did not change significantly in either group. There were no significant changes in any of the test variables in CON. In conclusion, this study shows that 6 weeks of 20-s or 180-s double poling interval training, three times a week, significantly increases power output in both 30-s and 6-min tests, as well as in selected physiological and biomechanical parameters in well-trained cross-country skiers.

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Introduction

In endurance sports there are at least three important physiological prerequisites: high aerobic power, the ability to use a high fraction of it over time, and good work efficiency; that is, low energy cost at race pace. It is well known that aerobic processes account for the majority of energy turnover in conventional cross-country ski races and that elite cross-country skiers are among the endurance athletes with the highest maximal aerobic power (Rusko et al. 1978; Åstrand and Rodahl 1986). Numerous studies have shown a strong positive correlation between maximal aerobic power and cross-country ski racing performance (see Saltin 1997). Recent studies have also emphasised the importance of upper-body power production (Bilodeau et al. 1995; Rundell 1995; Staib et al. 2000; Mahood et al. 2001) to predict cross-country ski performance. In running it has been shown that neuromuscular factors are related to performance (Paavolainen et al. 1999) and studies have shown an increase in endurance performance after strength training, despite there being no change in the maximum oxygen uptake ($\dot{V}O_{2max}$) (Hickson et al. 1980, 1988; Hoff et al. 1999). As described above, a number of studies have investigated different factors and training methods relevant for cross-country skiing performance. To our knowledge, no studies have investigated the effects of sport specific interval training on upper body power production in cross-country skiers.

The purpose of this study was to investigate the effect of upper body 20-s and 180-s interval training on upper body power output in cross-country skiers. Specifically, we wanted to discover whether there is a change in upper-body 30-s and/or 6-min power output and in selected physiological and biomechanical parameters after double poling interval training; and in particular whether 20-s sprint interval training has an effect on 6-min power output.

Table 1 Training group subject data, mean values and ranges

	Subjects (n)	Age (years)	Height (m)	Body mass) (kg)
20-s interval training group (IT20)	6	21 (19–24)	1.78 (1.73–1.84)	70 (62–72)
180-s interval training group (IT180)	7	26 (20–33)	1.76 (1.73–1.79)	69 (62–74)
Control group (CON)	7	25 (20–29)	1.80 (1.69–1.90)	74 (61–92)

Methods

Subjects

Twenty subjects (12 male and 8 female), well-trained regional-to-national-level cross-country skiers, completed the study. Written informed consent to participate was given by each subject and the study was approved by the regional ethics committee of the Norwegian Research Council for Science and the Humanities. The mean (SD) $\dot{V}O_{2\max}$ in the men was 67.3 (4.6) ml kg^{-1} min^{-1} and in the women was 54.5 (4.3) ml kg^{-1} min^{-1}, respectively. The subjects were divided into three mixed groups with reference to performance and gender. Two intervention groups: a 20-s interval training group (IT20; $n = 6$) and a 180-s interval training group (IT180; $n = 7$) were set up. For 6 weeks, they replaced their usual strength training regimes with interval training three times a week on a double poling ergometer. IT20 performed repeated tests of 20 s work and 120 s rest; IT180 undertook 180 s of work with 90 s rest. Over the training period the control group did not alter their training; their usual aerobic training remained the same as in the intervention groups and their strength training was not altered. Subject group data are presented in Table 1.

Apparatus and calibration procedures

The poling ergometer

The double poling performance tests before and after the training period, and the double poling training, were carried out on a rowing ergometer (Concept II C, Concept Inc., Morrisville, Vt., USA), which was modified to allow simulation of double poling in cross-country skiing (Fig. 1). The transducer system and the electronic device of the Concept II ergometer permitted calculation of average and peak power output.

Oxygen uptake and blood lactate concentration

Oxygen uptake was recorded on line with an automatic ergospirometric device (Oxycon Champion, Jaeger GmbH, Hoechberg, Germany). Ventilation was measured with a low-inertia, low-resistance, bi-directional rotating turbine flow sensor. Respired air was sampled by the apparatus from a mixing chamber for measurement of PO_2 and PCO_2. The investigator calibrated the turbine flow with a 3.0 l air syringe. Precision gas mixtures were used for calibrating the gas analysers. The time delay between the volume and gas-concentration signals was measured and compensated for. The equipment was calibrated before each test. Lactate concentrations in non-haemolysed blood samples (25μl) taken from a punctured fingertip were analysed with a semi-automatic device (YSI 1500 Sport, Yellow Spring Inc., Yellow Springs, Ohio, USA). The blood lactate analyser was calibrated before each test by using lactate standards.

Heart rate recording and ratings of perceived exertion

A heart rate monitor (Polar Sport Tester, Polar Electro OY, Kempele, Finland) was used, together with the rating of perceived exertion (RPE) scale (Borg et al. 1985), to evaluate the load at the different stages during the physiological tests. The subjects rated their perceived exertion in breathing as well as in arm and leg musculature.

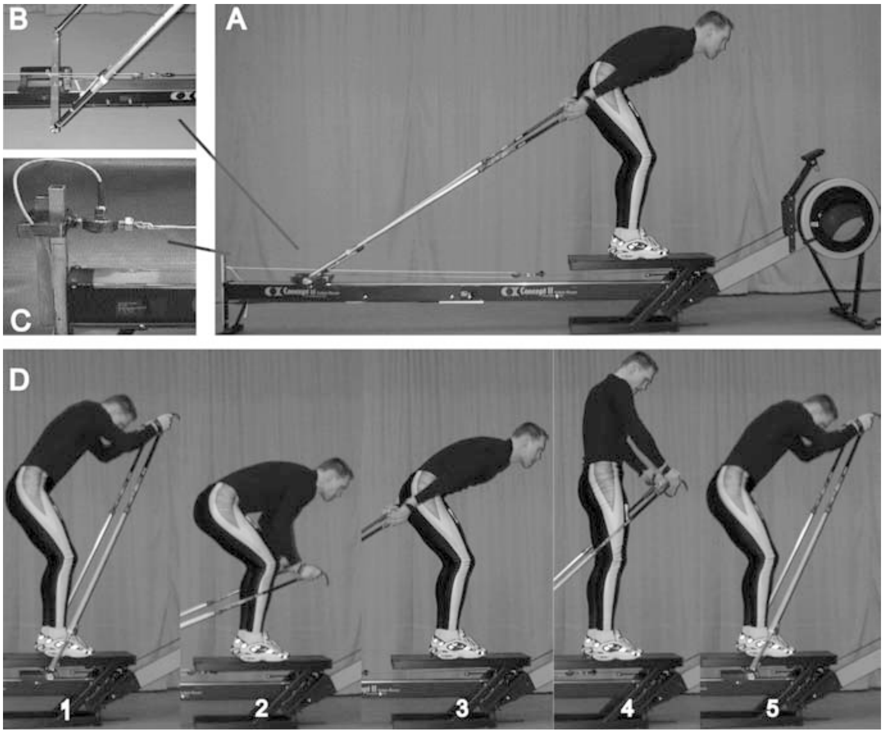

Fig. 1A–D The poling ergometer. Subject is standing on a podium above the slide rail while double poling on the ergometer (**A**). The poling ergometer has a metal bar mounted on the slide wagon with a pole attached on each side of this (**B**). The slide wagon is connected to a fixed pulley system with a cord. The pulley is connected to the chain, which drives the air friction braked flywheel via a cog-wheel. A force transducer is mounted at one end of the pulley system, at the end of the slide rail (**C**). This transducer continuously registers the force in the pulley system cord. (**D**) Double-poling cycle: D1–D3 and D3–D5 show the thrust and swing phases, respectively

Double poling force and cycle frequency

A force transducer (Transducer KRG-4T10, Nobel Elektronik, Karlskoga, Sweden) was used to continuously register the force in the poling ergometer pulley system (see Fig. 1C). The transducer was connected to an amplifier and the signals were A/D converted. The linearity and precision of the force transducer was checked by repeated control measurements with known weights from 5 to 60 kg. These measurements showed less than 1% linearity deviation over the whole measuring range. The force and temporal data from double poling during the last 5 s of each minute in the 6-min aerobic endurance test were analysed, the average of the six samples being calculated with computer software. The thrust phase onset and offset of the unfiltered force curve were marked with a cursor and the duration of the mean force of each pole thrust was calculated. The double poling cycle frequency was calculated from the force curve.

Test procedures

A. Base-line performance level

Before the pre-test each subject was introduced to the test procedures and how to use the double poling ergometer. Great effort was undertaken to familiarise all the subjects with poling on the machine. The subjects undertook at least four 15-min training sessions on the poling ergometer on separate days 2 weeks before the pre-test. Each session ended with a 60-s all-out test. Subjects were considered familiar with the poling technique on the ergometer when they levelled-off in average power (less than 5% difference) in at least two consecutive 60-s tests. In addition, all subjects participated once in the whole test procedure (see sub-sections B–D below) before the pre-test (Fig. 2). The extensive precautions presented above were undertaken to avoid any learning effect between the pre- and post-test. The tests (B–D) were performed on separate days with the same protocol before (pre-test) and after (post-test) the training period. The subjects were instructed to avoid heavy physical activity for 24 h, and food intake for 2 h, before the tests.

B. $\dot{V}O_{2max}$ during running

$\dot{V}O_{2\max}$ was measured during running on a motor-driven treadmill (ELG70, Woodway GmbH, Weil am Rein, Germany). After a standardised 20-min warm up period, the male and female subjects started to run at 11 km h^{-1} and 9 km h^{-1}, respectively. All subjects ran at a constant inclination of 10.5%, with a stepwise increase in the speed each minute until exhaustion. Speed was increased following the same protocol in both the pre- and post-test. Respiratory exchange ratio >1.1, eventual levelling off in oxygen uptake, heart rate data and RPE were used as criteria to determine $\dot{V}O_{2\max}$.

C. Work efficiency, blood lactate concentration and peak oxygen uptake during double poling

Work efficiency, defined as $\dot{V}O_2$ at a given work load, and blood lactate concentration were determined at each stage in a stepwise incremental test on the poling ergometer. Prior to a 10-min warming-up period and the test, a blood sample was obtained from a fingertip to determine blood lactate concentration at rest. The incremental test for females started at 40 W and increased in 20 W steps, every 4th min. The males started at 50 or 75 W and the work rate was increased by 25 W every 4th min. The air resistance of the flywheel, which was scaled from 0–10, was set at 0 for the female subjects and 5 for the male subjects. Between each sub-maximal work stage 30 s rest was allowed, when blood lactate samples were obtained. The work rate was increased stepwise until the blood lactate concentration increased by more than 1.5 mmol l^{-1} above the resting value. The 100 and 150 W 4-min stage tests on the double poling ergometer were selected for the females and males, respectively, to compare eventual training effects on work efficiency and blood lactate concentration. After 5 min rest, peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) was determined during double poling on the poling ergometer. This was done by increasing the work intensity by 25 W from the individual starting levels each minute for the first 3 min of the test and subsequently every 30 s at higher intensity levels, until exhaustion. Respiratory exchange ratio >1.1, eventual levelling off in oxygen uptake, heart rate data and RPE were used as criteria to determine $\dot{V}O_{2\text{peak}}$. The same individual protocol for increase in workloads was used in the pre- and post-tests.

D. Power output in the 30-s and the 6-min performance tests

The pre- and post-training ergometer tests were designed to determine the highest possible performance during 30 s and 6 min. Prior to the tests the subjects were allowed a warming-up period of 5 min on the poling ergometer. The power output in 30-s maximum-effort test and 6-min all-out test were recorded. The tests were designed as time-trial ("closed end") tests. Video recordings were performed in the sagittal plane, both pre- and post-test, in order to check for qualitative changes in poling technique. The video recordings were evaluated by means of a video analysis system by two researchers independently.

Training

The IT20 and IT180 training groups performed an average of 16 training sessions on the poling ergometer during a period of 6 weeks (Fig. 2). The IT20 group progressively increased the number of their 20-s maximum work intervals from 11.7 to 14.7 over the training period, with a 120-s rest period between each interval. Each interval was performed with maximum effort. The IT180 group started with six 180-s work intervals and 90-s rest periods and increased to 7.5 intervals by the end of the training period. The intensity level during the work intervals for IT180 started at 85% of the average power produced in the 6-min performance pre-test. The absolute training power level increased by 14% during the training period to adjust for an increase in performance. The average total weekly training durations were 8.4, 8.1 and 8.6 h for IT20, IT180 and CON, respectively. The training for all participants was continuously directed and supervised by the experimenters regarding quantity and intensity, and all training sessions during the period were documented. The relative training time for the intervention and control groups are summarised in Fig. 3. The investigation, including the training period, was carried out during May and the first half of June, when the subjects were recovered from the competitive season and adjusted to the subsequent training level. It was decided to intervene at this time of the year during a steady-state training period with a stable load of predominantly low-intensity aerobic training performed as roller skiing, running with and without poles and cycling.

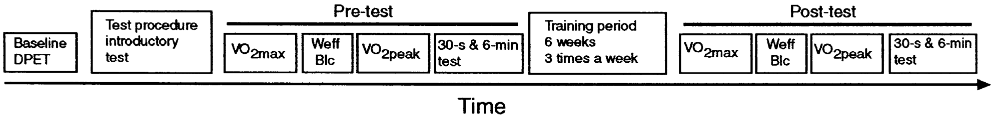

Fig. 2 Schematic description of the study design. *DPET* Double poling ergometer training; *Weff* work efficiency; *Blc* blood lactate concentration

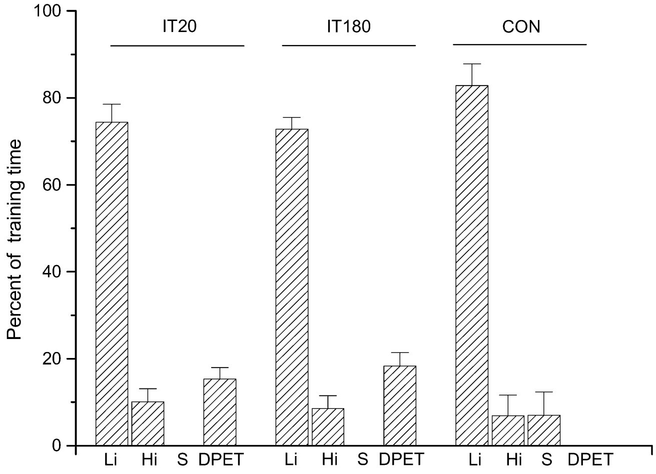

Fig. 3 Mean relative duration (SD) of training time. *IT180* 180-s interval training; *IT20* 20-s sprint interval training, and *CON* control group. *Hi* High intensity training > 75% maximum oxygen uptake; *Li* low intensity training < 75% maximum oxygen uptake; *S* strength training; *DPET* double poling ergometer training

Statistics

Statistical calculations were performed with a software package (Statistica, version 5.5, StatSoft Inc., Tulsa, Okla., USA). All data are reported as mean and standard deviation (SD). Associations between the parameters investigated were calculated with Pearson product-moment correlation analysis. To evaluate possible differences in the pre-test of the sample groups in the performance tests, Kruskal-Wallis ANOVA and MANCOVA with body mass as co-variate were performed. Wilcoxons non-parametric matched-pairs signed-ranks test was used to determine statistical difference within the sample groups between the pre- and post-test. The significance level was set at 0.05.

Results

Power output during the 30-s and the 6-min performance tests

The evaluation of the power output in the 30-s and 6-min performance tests revealed no significant differences between the three investigated groups in the pre-test. In the pre-test, the correlation coefficient between peak and mean power in the 30-s test was 0.99 ($n = 20$). The correlation coefficient between peak and mean power in the 30-s test versus mean power in the 6-min test was 0.93 ($n = 20$). Peak and mean power during the 30-s test and mean power during the 6-min test increased significantly ($P < 0.05$) between the pre- and post-test in both IT20 and IT180 (Table 2). There was no difference between pre-and post-test for CON.

Average force and poling cycle frequency

Average poling force during the 6-min test increased significantly ($P < 0.05$) for IT180 after training, while no significant change was observed for IT20 and CON (Table 2). Average poling cycle frequency in the pre-test ranged within approximately 48–49 cycles min^{-1} in all three groups, which corresponds to a cycle duration of 1.25–1.21 s. A significant increase in cycle frequency during the 6-min test was seen for IT20 after the training period ($P < 0.05$) while IT180 and CON showed no significant changes.

$\dot{V}O_{2\text{max}}$ and $\dot{V}O_{2\text{peak}}$

There was no significant change in $\dot{V}O_{2\text{max}}$ between the pre- and post-test in any of the groups (Table 2). $\dot{V}O_{2\text{peak}}$ increased in IT180 after training ($P < 0.05$) but not in IT20 and CON (Table 2). The relative utilisation of $\dot{V}O_{2\text{max}}$ during double poling (i.e. the ratio between $\dot{V}O_{2\text{peak}}$ and $\dot{V}O_{2\text{max}}$) varied between 84 and 86% in the pre-test. No significant change was seen in this ratio after the training period. The correlation coefficient between $\dot{V}O_{2\text{peak}}$ during double poling and mean power during the 6-min performance test for all subjects was 0.92.

Work efficiency and blood lactate concentration

$\dot{V}O_2$ during double poling in the post-test at the specific sub-maximal workloads decreased in IT20 and IT180 ($P < 0.05$) compared to $\dot{V}O_2$ in the pre-test; in other words, their work efficiency improved. Blood lactate concentration during double poling at sub-maximal levels decreased in IT180 ($P < 0.05$) but not in IT20 and CON (Table 2).

Discussion

This study showed that well-trained cross-country skiers increased power output after 6 weeks of interval training on a double poling ergometer. Interestingly, the results showed that sprint-like 20-s interval training significantly improved power output during the 6-min test and that 180-s interval training significantly improved power output in the 30-s performance test. No significant changes occurred in the control group in any of the investigated variables.

Methodological considerations

In this study we emphasised a base-line period for the subjects, who already had a good double poling technique, in order for them to become familiar with the double poling ergometer before the intervention period. This was done to avoid the influence of a learning effect during the double poling interval training. Thus, the subjects underwent several training sessions on the poling ergometer on separate occasions during the weeks before the pre-test. We also chose to use “closed end”

Table 2 Mean (SD) pre- and post-training results. Peak power and mean power in the 30-s test and mean power, force and cycle frequency in the 6-min performance test. Peak and maximum oxygen uptake as well as work efficiency and blood lactate concentration during double poling at sub-maximal work intensities. The body mass did not change significantly within any of the groups between the pre- and post-test

	20-s interval training (IT20)			180-s interval training (IT180)			Control (CON)		
	$n=6$			$n=7$			$n=7$		
	Pre-training	Post-training	% change	Pre-training	Post-training	% change	Pre-training	Post-training	% change
Mean power, 30 s (W kg^{-1})	2.94 (0.65)	3.58 (0.94)	21* (16)	2.73 (0.55)	3.19 (0.59)	17* (5)	3.32 (0.74)	3.35 (0.82)	1 (6)
Peak power, 30 s (W kg^{-1})	3.49 (0.72)	4.28 (1.08)	22* (14)	3.11 (0.64)	3.65 (0.66)	17* (7)	3.81 (0.84)	3.86 (0.85)	1 (5)
Mean power, min (W kg^{-1})	1.91 (0.40)	2.07 (0.47)	8* (8)	1.86 (0.47)	2.13 (0.44)	16* (10)	2.09 (0.43)	2.06 (0.35)	−1 (5)
Average force, 6 min (N kg^{-1})	1.63 (0.36)	1.72 (0.29)	7 (8)	1.64 (0.32)	1.82 (0.30)	15* (11)	1.75 (0.42)	1.78 (0.38)	2 (15)
Cycle frequency, 6 min (c min^{-1})	48.2 (3.9)	53.6 (2.9)	12* (9)	49.4 (3.7)	51.3 (4.4)	4 (6)	48.4 (8.2)	50.3 (7.0)	4 (6)
$\dot{V}O_{2\max}$ (ml kg^{-1} min^{-1})	63.8 (9.9)	64.5 (10.3)	1 (4)	61.6 (7.1)	62.4 (8.0)	1 (2)	63.4 (6.2)	62.9 (5.5)	−1 (4)
$\dot{V}O_{2\text{peak}}$ ml kg^{-1} min^{-1})	54.2 (10.5)	53.4 (9.6)	−1 (4)	53.0 (7.3)	55.2 (7.8)	4* (3)	53.7 (6.0)	52.4 (4.5)	−2 (5)
Work efficiency[a] (ml kg^{-1} min^{-1})	44.6 (6.1)	40.6 (6.4)	−9* (6)	44.0 (4.8)	41.0 (4.6)	−7* (5)	40.0 (5.5)	39.5 (6.2)	−2 (5)
Blood lactate concentration (mmol l^{-1})	4.6 (1.8)	4.1 (1.3)	−4 (8)	3.8 (1.0)	3.1 (0.8)	−18* (9)	3.2 (1.2)	3.2 (1.3)	0 (24)

* Variable significantly different between pre- and post-test, $P < 0.05$

[a] At the 100 and 150 W stage for females and males, respectively

performance tests (30-s and 6-min) to examine changes in performance, as opposed to the more commonly used "open end" (time-to-exhaustion) performance test. Jeukendrup et al. (1996) showed that in a long closed end test (approximately 60 min) there was a considerably lower coefficient of variation than in an open end test and they speculated that an open end test could be more influenced by psychological factors than in a test where the endpoint is known. The non-significant changes in performance in the control group from pre- to post-test suggest that no significant further learning of the poling technique was present between these tests. However, it cannot be excluded that learning effects can have some influence in the results of the intervention groups.

Effects of 20-s maximum interval training

IT20 significantly improved mean power in the 30-s double poling test (Table 2). In addition, our data show a strong correlation ($r = 0.99$) between peak and mean power during the 30-s test. The improved 30-s performance after 20-s interval training was expected with reference to data from, for example, Sharp et al. (1986) and Troup et al. (1986), which had previously shown that high-intensity sprint training leads to improvements in the rate of anaerobic energy production and power output.

The improved power output for IT20 in the 6-min test was accompanied by an improved work efficiency. In a previous study, Hoff et al. (1999) found an enhanced poling performance accompanied by improved work efficiency and higher rate of force production after heavy resistance strength training of the upper body. It is reasonable to assume that the maximum effort of poling in the IT20 group increased the rate of force production in the pole thrusts, which in turn might have improved work efficiency. However, in order to test this assumption, future research on maximum rate of force production is needed. IT20 undertook their 20-s intervals with a high cycle frequency and power output related to their maximum effort in every bout. This can be compared to the IT180 group who trained at a lower and more similar power level and cycle frequency to the one used during the 6-min test. This specificity in training concerning force output and cycle frequency may explain why the groups developed different force/frequency strategies during the aerobic performance test. Qualitative analysis of video recordings obtained during the pre- and post-test revealed no differences in gross movement patterns. Further support for the possible importance of high anaerobic power output for endurance performance is given in a number of studies on different sports. For example Bulbulian et al. (1986) showed that anaerobic power was a critical determinant for race success among cross-country runners who have similar $\dot{V}O_{2\max}$. Tanaka et al. (1993) have shown that more highly ranked cyclists had significantly higher anaerobic power output compared to lower ranked cyclists. Furthermore, the strong correlation ($r = 0.93$) between power output during the 30-s test and the 6-min test supports the view that performance in these two tests may be related. During a 6-min performance test, high lactate levels and a substantial hydrogen ion production, which should be expected, would lower pH and inhibit skeletal muscle contractility if not buffered (Mainwood and Renaud 1985). In addition, Weston et al. (1997) have shown a strong correlation between buffering capacity and performance in an aerobic endurance test (40-km time-trial in a group of well-trained cyclists). Stepto et al. (1999) and Laursen and Jenkins (2002) have reported that cyclists performing repeated supramaximal (above $\dot{V}O_{2max}$) cycling interval training enhanced peak power output and endurance performance. The factors presented above can all contribute to an explanation of the improved performance in the 6-min test by IT20 in our study. Obviously, there seem to be factors in addition to high $\dot{V}O_{2max}$ that are important for high aerobic performance. These factors have been named muscle power factors (Paavolainen et al. 1999; Rusko 2002) and have been proposed to be related to the capability of the neuromuscular system to produce power when the oxygen uptake and/or acidity are high. They have found anaerobic muscle power (the highest 20-s running velocity during an incremental maximum anaerobic running power test) to be strongly correlated with race performance and also differentiates between successful and less successful skiers with similar maximal oxygen uptake and anaerobic threshold (see Rusko 2002).

Effects of 180-s interval training

The increase in 6-min performance after 180-s interval training was expected. The IT180 group significantly improved their $\dot{V}O_{2peak}$ with an unchanged $\dot{V}O_{2max}$, and lowered their blood lactate concentration after the training period. The importance of a high $\dot{V}O_{2peak}$ during double poling for performance in cross-country skiing has been demonstrated by Mygind et al. (1994). This was supported in our study by the strong correlation ($r = 0.92$) between $\dot{V}O_{2peak}$ and mean power in the 6-min performance test. It seems logical to assume that the specific 180-s interval training, using double poling, employed in this investigation stimulated adaptation mainly in the upper body, indicated by increased $\dot{V}O_{2peak}$. The fact that a relatively short period (6 weeks) of this type of training led to significant improvement of $\dot{V}O_{2peak}$, in already well-trained cross-country skiers, points to the potential of specific double poling training as a possible intervention to improve important performance factors in cross-country skiing. $\dot{V}O_{2max}$ did not improve, which may be related to the skiers' already high $\dot{V}O_{2max}$ and/or that the training duration, intensity and muscle mass with predominantly upper body work was not enough to increase it. The IT180 group significantly improved work efficiency; that is, the same absolute work intensity cost less oxygen after the intervention period, simultaneously with increased poling force during the 6-min test, with no significant change in poling frequency. An increase in poling force would theoretically make it possible to decrease the relative force by each poling thrust to a lower percentage of the maximal at a given sub-maximal work intensity, allowing an increased participation of slow-twitch fibres and a reduced rate of fast-twitch fibre recruitment (Hickson et al. 1988). This may have resulted in an improved work efficiency and a lower blood lactate concentration during the sub-maximal steady state workloads in the double poling tests for the IT180 group.

It might be somewhat surprising that 180-s interval double poling training also improved 30-s power output, and to our knowledge this is the first study to report this. Previously, Lindsay et al. (1996) demonstrated that, in cyclists, an interval program with repeated 5-min work bouts improved short maximal exercise lasting approximately 60 s. Their explanation was that the contribution of aerobic energy release to the total energy requirements in a test as short as 60 s is relatively high (~50%). It has been shown that the contribution from the aerobic energy system during a single 30-s test is approximately 29% (Bogdanis et al. 1996). The improved performance in the 30-s test by the IT180 training group might be related to an increased $\dot{V}O_{2peak}$, but a more plausible explanation might be an improved buffering capacity in the upper body. Even if the 3-min intervals are predominantly aerobic, the remaining contribution from the anaerobic energy system during 3-min intervals may also lead to significant anaerobic adaptations. This possibility is supported by a study of Weston et al. (1997), which showed that high intensity interval training (5-min work bouts) significantly improved buffering capacity in well-trained cyclists.

Conclusion and practical considerations

This study showed that 6 weeks of 20-s or 180-s double poling interval training, three times a week, significantly increased power output in both 30-s and 6-min tests, as well as in selected physiological and biomechanical parameters. The significant improvement in the 6-min test, in both IT20 and IT180, indicates that upper body power training might usefully contribute to improvements in performance in cross-country skiing. With reference to the training effects found in our study, we suggest that cross-country skiers in general, and sprint skiers in particular, may integrate the interval models used in this study in their training program. The sprint discipline consists of 4–5 heats of ~3-min high intensity work in each heat, where double poling is one of the most dominant techniques. However, the specific relevance of double poling ergometer training for cross-country skiing in the field condition on snow still remains to be investigated.

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