Eur J Appl Physiol (2010) 109:1077–1086
DOI 10.1007/s00421-010-1455-1

ORIGINAL ARTICLE

Block training periodization in alpine skiing: effects of 11-day HIT on $VO_{2\max}$ and performance

**Fabio A. Breil · Simone N. Weber · Stefan Koller ·
Hans Hoppeler · Michael Vogt**

Accepted: 22 March 2010 / Published online: 4 April 2010

Abstract Attempting to achieve the high diversity of training goals in modern competitive alpine skiing simultaneously can be difficult and may lead to compromised overall adaptation. Therefore, we investigated the effect of block training periodization on maximal oxygen consumption ($VO_{2\max}$) and parameters of exercise performance in elite junior alpine skiers. Six female and 15 male athletes were assigned to high-intensity interval (IT, $N = 13$) or control training groups (CT, $N = 8$). IT performed 15 high-intensity aerobic interval (HIT) sessions in 11 days. Sessions were 4 × 4 min at 90–95% of maximal heart rate separated by 3-min recovery periods. CT continued their conventionally mixed training, containing endurance and strength sessions. Before and 7 days after training, subjects performed a ramp incremental test followed by a high-intensity time-to-exhaustion (tlim) test both on a cycle ergometer, a 90-s high-box jump test as well as counter-movement (CMJ) and squat jumps (SJ) on a force plate. IT significantly improved relative $VO_{2\max}$ by 6.0% ($P < 0.01$; male +7.5%, female +2.1%), relative peak power output by 5.5% ($P < 0.01$) and power output at ventilatory threshold 2 by 9.6% ($P < 0.01$). No changes occurred for these measures in CT. tlim remained unchanged in both groups. High-box jump performance was significantly improved in males of IT only (4.9%, $P < 0.05$). Jump peak power (CMJ −4.8%, SJ −4.1%; $P < 0.01$), but not height decreased in IT only. For competitive alpine skiers, block periodization of HIT offers a promising way to efficiently improve $VO_{2\max}$ and performance. Compromised explosive jump performance might be associated with persisting muscle fatigue.

Keywords High-intensity interval training · Block periodization · Endurance performance · Ventilatory threshold · Alpine skiing

Introduction

Alpine skiing demands high technical skills, leg strength, dynamic ability, aerobic and anaerobic capacity (Andersen and Montgomery 1988). Although anaerobic energy source contributes half of the energy for performance, elite skiers achieve 80–90% of maximal oxygen uptake capacity ($VO_{2\max}$) during a race, whereas depending on the discipline, exercise intensity lies between 120 and 250% of $VO_{2\max}$ in these events (Veicsteinas et al. 1984; Vogt et al. 2005). Accordingly, several studies have reported high $VO_{2\max}$ in alpine skiers as compared to the normal population (Brown and Wilkinson 1983; Rusko et al. 1978) with values above 65 ml $\mathrm{kg}^{-1}\,\mathrm{min}^{-1}$ (Karlsson et al. 1978; Neumayr et al. 2003; Tesch 1995; Veicsteinas et al. 1984). Furthermore, it was shown that international success in alpine skiing correlates strongly with a high aerobic capacity (Neumayr et al. 2003; Veicsteinas et al. 1984).

Communicated by Susan Ward.

F. A. Breil (✉) · S. N. Weber · H. Hoppeler · M. Vogt
Institute of Anatomy, University of Bern,
Baltzerstrasse 2, 3000 Bern 9, Switzerland
e-mail: fabio.breil@ana.unibe.ch

F. A. Breil · S. N. Weber
Exercise Physiology,
Institute of Human Movement Sciences,
ETH Zurich, Zurich, Switzerland

S. Koller
Institute of Sport and Sport Sciences,
University of Basel, Basel, Switzerland

Owing to the requirements of the training process, including much time devoted to on-snow training, not much time remains for an effective periodization of endurance training in alpine skiing. Rather, endurance and strength sessions are typically performed in parallel and such mixed training, including high strength and endurance training loads, may result in compromised improvement for both modalities as well as an increased risk of overtraining (Myburgh 2003). Several studies have shown curbed adaptations in various sports when strength and endurance are trained simultaneously, as compared to consecutively (Glowacki et al. 2004; Nader 2006). Furthermore, Kutedakis et al. (Koutedakis et al. 1992) reported reduced maximal aerobic power and anaerobic threshold with intense mixed training in elite alpine skiers. Alternative training concepts using block periodization attempt to avoid these concurrent effects by focusing on a single training aspect while maintaining others (Issurin 2008; Pyne and Touretski 1993). Block periodization could thus provide a better strategy for improving physiological variables such as strength and endurance in the preparation period to desired levels (Issurin 2008).

Several studies indicate that high-intensity interval training (HIT) improves endurance capacity more effectively than submaximal training in sedentary and recreationally active individuals (Helgerud et al. 2007; Laursen and Jenkins 2002). Further, although endurance-related variables, such as $VO_{2\max}$ and anaerobic threshold are difficult to enhance in well-trained athletes through additional increases in submaximal training volume (Londeree 1997), $VO_{2\max}$ was improved by 4.9–8.1% in well-trained cyclists and runners after HIT performed 2–3 times per week for 3–8 weeks (Laursen et al. 2002; Smith et al. 1999). Thus, it seems that for trained athletes, training at or very close to $VO_{2\max}$ is an effective stimulus to further enhance $VO_{2\max}$ (Laursen and Jenkins 2002; Londeree 1997; Midgley et al. 2006). Various HIT protocols have successfully been used for improving endurance performance and corresponding physiological variables (Laursen and Jenkins 2002; Laursen et al. 2002). Depending on the duration, intensity and frequency of the high-intensity bouts, the magnitude of training adaptations may differ. However, it was shown that either very short (15–30 s) supramaximal intervals up to 175% of peak power output (PPO) or maximal speed ($V_{\max}$) (Billat 2001; Laursen et al. 2005; Smith et al. 1999) and longer (4–6 min) intervals at ~80% PPO improve aerobic as well as anaerobic variables (Billat 2001; Helgerud et al. 2007; Lindsay et al. 1996; Stepto et al. 1999).

Several recent studies have focused on the effectiveness of HIT protocols, employing sessions of 4 × 4 min at 90–95% $HR_{\max}$ separated by 3 min of active recovery. These have consistently improved $VO_{2\max}$ and sports-specific skills in trained soccer players (Helgerud et al. 2001, 2007; Hoff et al. 2002; McMillan et al. 2005). Hoff et al. (2002) argued that continuous interval training with an intensity of 90–95% $HR_{\max}$ should improve $VO_{2\max}$ by increasing stroke volume and maximal cardiac output due to extended time periods where the cardiovascular system is pushed at $VO_{2\max}$. Although most studies have investigated cycling or running regimes, continuous dribbling on a track was also found to be successful in soccer players (Helgerud et al. 2001; Hoff et al. 2002) showing that sport-specific training modalities can be used, if carried out at high intensities.

For endurance athletes, two HIT sessions per week combined with aerobic base training seem to be well tolerated, while three or more HIT sessions per week over extended time periods have been shown to induce overtraining symptoms (Billat et al. 1999). In contrast, severe increase in HIT volume for several consecutive days followed by sufficient recovery, i.e. so-called *shock* microcycle seem to provide a very time-efficient way for improving aerobic capacity (Issurin 2008). To date, only Stolen et al. (2005) in their review presented preliminary results on such a *shock* microcycle, in which a Norwegian second division football team performed 13 HIT sessions within 10 days. The 1–2 HIT sessions per day were executed on a dribbling track just after the regular soccer training (Helgerud et al. 2001; Hoff et al. 2002). $VO_{2\max}$ could be improved by 7.3%, illustrating the possibility to significantly improve the aerobic capacity of trained athletes within <2 weeks (Stolen et al. 2005).

The aim of this study was to test the effect of high-intensity training according to block periodization on the aerobic capacity in junior alpine skiers. It was hypothesized that an 11-day *shock* microcycle including 15 HIT sessions would elicit greater improvement in $VO_{2\max}$, PPO and submaximal values than conventional mixed training.

Methods

Subjects

Twenty-two trained elite junior alpine skiers from a national training centre were recruited to take part in this study. One male athlete dropped out due to a medical condition not related to the study intervention. The remaining 15 males and 6 female subjects had trained for more than 3 years and were competing nationally at FIS races. After being informed of the aims and possible risks of the investigation, subjects gave written consents to participate in all procedure, which were approved by the Ethics Committee of Bern, Switzerland (KEK-Nr. 43/08). Normal ECG and the absence of cardiac and pulmonary disease were confirmed for all subjects, whose characteristics are presented in Table 1.

Table 1 Characteristics and anthropometric data of the subjects before and 7 days after training intervention

	IT			CT		
	Before training	7 days after training	*N*	Before training	7 days after training	*N*
Age (years)	17.4 ± 1.1		13	16.6 ± 1.1		8
Height (cm)	172.6 ± 10.5		13	173.9 ± 9.4		8
Body mass (kg)	66.0 ± 11.0	65.3 ± 10.9*	13	69.3 ± 9.7	69.1 ± 10.4	8
Body fat_all (%)	11.8 ± 7.4	12.0 ± 7.9	13	11.7 ± 6.6	11.6 ± 6.4	8
Body fat_male (%)	7.5 ± 3.0	7.5 ± 2.7	9	8.5 ± 3.7	8.6 ± 3.5	6
Body fat_female (%)	21.4 ± 4.3	22.1 ± 5.9	4	21.1 ± 0.7	20.7 ± 1.2	2
BMI_all	22.1 ± 2.3	21.8 ± 2.2	13	22.9 ± 2.6	22.8 ± 2.6	8
BMI_male	22.2 ± 2.7	22.0 ± 2.5	9	23.1 ± 2.9	23.1 ± 3.0	6
BMI_female	21.8 ± 1.3	21.5 ± 1.4	4	22.4 ± 1.7	21.8 ± 0.9	2

Parameters are shown as mean ± SD

IT high-intensity training group, *CT* control training group

* Significant difference compared to before training ($P < 0.05$)

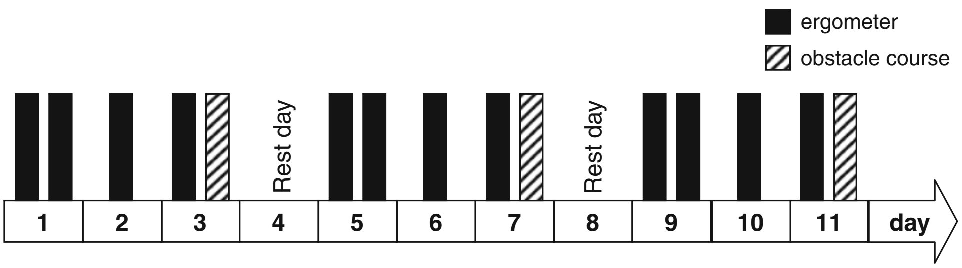

Fig. 1 Arrangement of the 15 HIT sessions over the 11-day *shock* microcycle

Experimental design

The investigation was conducted during the athletes' off-season preparatory period. The intervention period was carefully planed and in agreement with the involved coaches. All tests were performed under controlled conditions at the national training centre in Engelberg at an altitude of 1,050 m above sea level. Following familiarization to performance testing, high-intensity interval training (IT, $N = 13$) and control training (CT, $N = 8$) groups were matched for $VO_{2\max}$ and subsequently showed not differ for age, anthropometrics, peak power output (PPO) and jump performance. Subjects continued their normal training for 3 weeks prior to pre-intervention testing. Immediately after pre-intervention testing, both groups were exposed to an 11-day training intervention. Post-intervention testing took place 7 days after intervention. Athletes were instructed to avoid strenuous exercise for 24 h before all testing.

Training program

Following pre-testing, the 11-day training intervention began, in which IT performed a total of 15 high-intensity interval sessions within three 3-day training blocks. Training blocks were separated by a rest day each (Fig. 1). Each HIT session consisted of four 4-min interval bouts at an intensity eliciting 90–95% of the individual maximal heart rate ($HR_{\max}$), separated by 3-min active recovery periods (Fig. 2). The HIT sessions were performed either on a cycle ergometer (12 sessions) or on a ski-specific obstacle running course containing slalom, balancing and jumping elements (3 sessions). HIT intensity was controlled by continuous heart rate monitoring, periodic ratings of perceived exertion (6–20 Borg scale) and blood lactate measurements. HIT sessions were supervised and performed in groups of 6–7 athletes. A standardized 8-min warm-up including three 15-s sprints was performed before all HIT sessions. During the intervention period, athletes continued normal core and upper-body strength training, and performed a leg strength session on each of the two rest days. Athletes in CT continued their normal endurance and strength training during the intervention period, representing the conventional training regime during this training period. Training data for both groups were recorded and total training loads were determined as rating of perceived exertion (1–10) multiplied with total training session time in min, according to the method of Foster (Foster et al. 2001). During the pre-intervention period, CT and IT did not differ in their mean weekly volume of endurance (IT 3.2 ± 1.8 h; CT 2.3 ± 2.0 h) and strength training (IT 3.0 ± 1.5 h; CT 3.8 ± 1.0 h).

Testing

Athletes completed all tests at the same time of day and in the same order. At both test days, anthropometric data were

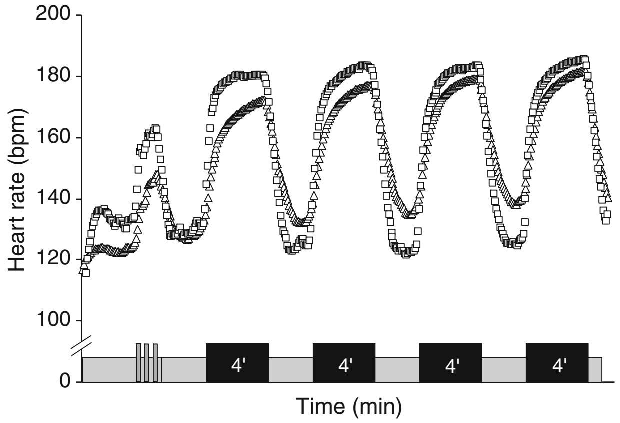

Fig. 2 Heart-rate kinetics to 4 × 4-min HIT protocol when performed on the cycling ergometer (*open triangle*) or on the ski-specific obstacle course (*open square*)

gathered before breakfast. Body fat content was calculated from 7-point skin fold measurement in triplicate (Jackson and Pollock 1978; Jackson et al. 1980) using a calibrated skin fold calliper (GPM, Switzerland). On the same day following breakfast and a 20-min warm-up, vertical jump height (H) and peak power (P) in countermovement (CMJ) and squat jump (SJ) were tested using a Quattro Jump force plate (Kistler Instruments, Winterthur, Switzerland) and accompanying software (Version 1.07).

All endurance exercise tests were performed on a calibrated Ergometrics 800S cycle ergometer (Ergoline GmbH, Bitz, Germany). After 2-min of rest and 3-min of unloaded cycling, an individualized ramp incremental exercise test to exhaustion began for determining maximal oxygen consumption ($VO_{2\max}$), peak power output (PPO) and the first and second ventilatory thresholds (VT_1, VT_2). Work load increased 5–7 W every 10 s, depending on athlete's body weight and estimated endurance capacity. Breath-by-breath respiratory data were collected using a calibrated spirometry system (Oxycon Alpha, Erich Jäger GmbH, Würzburg, Germany) and averaged to detect ventilatory thresholds (15-s intervals) and maximal values (30-s intervals). Before each test, the volume transducer was calibrated using a 2-l calibration syringe and the CO_2 and O_2 gas analyzers were calibrated automatically using a known gas mixture. Heart rate (HR) was measured continuously by telemetry (Accurex Plus; Polar Electro, Kempele, Finland) and blood lactate concentration (Lac) was measured at the fingertip at rest, 4, 6, 8 min into the test, and immediately ($Lac_{\max}$) and 3 min after exhaustion (Biosen C-line sport, EKF-diagnostic GmbH, Barleben/Magdeburg, Germany). Rating of perceived exertion (RPE) using the Borg scale was evaluated every 2 min and at exhaustion. Athletes were verbally encouraged, but did not see actual work rate or elapsed time. The test was terminated at voluntary exhaustion or when cadence fell below 60 rpm. There was a 3-min recovery period following the incremental test, after which a maximal high-intensity time-to-exhaustion test (tlim) began. tlim began with 90 s cycling at 40%, after which work load was abruptly increased up to 90% of the athlete's pre-intervention PPO. Athletes were verbally encouraged to maintain a pedaling cadence above 60 as long as possible at this work load. When subjects stopped or cadenced below 60, the test was terminated and time-to-exhaustion was recorded in seconds.

VT_1 and VT_2 were determined by two independent investigators according to combined methods described elsewhere (Gaskill et al. 2001). Investigators were blinded to each other's analyses, and in the event of disagreement, the opinion of a third reviewer was solicited. $VO_{2\max}$ was the highest 30-s average and PPO was the final work rate attained during the incremental test.

Before and 7 days after intervention, athletes performed a 90-s high-box jumping test. This test is a part of the official "Swiss-Ski Power Test". Athletes were, therefore, familiar with the demands and goal of the test, which was to perform as many jumps as possible within 90 s up onto a 44-cm box while alternating right-to-left upon jumping down. The number of jumps was recorded every 30 s.

Statistical analysis

All results are presented as mean ± standard deviation (SD). Differences between the baseline measurements of both groups were tested using a two-tailed Student's *t* test for unpaired samples. Changes between pre- and post-intervention in the groups and for gender-specific adaptations were tested for significance by two-tailed Student's *t* test for paired samples. A two-way analysis of variance (ANOVA) with repeated measurement on two factors (intervention × time) was used to compare differences between groups and genders. Where significant differences were present, a Tukey's honestly significant difference post hoc test was used to allocate significant differences. Differences in groups' training log data were tested using a two-tailed Student's *t* test for unpaired samples. All statistics were run on STATISTICA Version 6.1 software package for Windows (Statsoft Inc., Hamburg, Germany). The results were accepted as significant at $P < 0.05$.

Results

Training intervention

Body mass was reduced in IT only (−1.0%, $P < 0.05$; Table 1). There were significant differences between groups in the total volume of endurance (CT 9.1 ± 5.3 h, IT

Table 2 Training data during high-intensity interval sessions

	Block I	Block II	Block III
Work load (W)	236 ± 49	238 ± 49	241 ± 51*
%HR$_{max}$	94.4 ± 2.3	93.3 ± 2.4**	92.9 ± 2.3**
Lac$_4$ (mmol L^{-1})	9.5 ± 2.2	10.2 ± 1.7	11.4 ± 1.6**
RPE$_1$	14.9 ± 1.2	14.5 ± 0.9	14.4 ± 1.3
RPE$_4$	18.5 ± 1.1	17.7 ± 0.8	17.9 ± 0.9*

Parameters are shown as mean ± SD

%HR$_{max}$ percent of pre-training maximal heart rate attained at the end of the 4-min intervals, *Lac$_4$* blood lactate after the fourth interval, *RPE$_{1/4}$* rating of perceived exertion after the first and fourth intervals

* Significant difference compared to block I ($P < 0.05$)

** Significant difference compared to block I ($P < 0.01$)

10.4 ± 1.2 h; $P < 0.01$) and strength training (CT 8.6 ± 3.5 h, IT: 2.7 ± 2.2 h; $P < 0.01$) during the 11-day intervention period. Total training volume was significantly lower in the IT group (CT: 23.9 ± 5.6 h, IT: 13.9 ± 2.7 h; $P < 0.01$). Weighted mean session RPE for endurance training sessions was higher in IT compared with CT (8.3 ± 1.1 vs. 5.7 ± 1.3; $P < 0.01$), whereas total training load was not different between groups (IT 6,328 ± 1,388, CT 8,119 ± 2,812).

Mean cycling work load during HIT sessions increased significantly by 2.2% ($P < 0.05$), whereas relative training intensity (%HR$_{max}$) decreased significantly by 1.5% over the course of intervention ($P < 0.01$; Table 2). Increases in blood lactate (Lac$_4$; $P < 0.01$) and decreases in ratings of perceived exertion (RPE$_4$; $P < 0.05$) were also observed after the fourth intervals.

Incremental exercise test

Maximal values

VO_{2max} relative to body mass was significantly improved by 6.0% ($P < 0.01$) in IT, whereas CT showed no significant change. Absolute VO_{2max} increased significantly in both groups (IT +5.1%, $P < 0.01$; CT +2.4%, $P < 0.05$). Only IT showed significantly higher post-intervention values for relative (+5.5%, $P < 0.01$) and absolute PPO (+4.4%, $P < 0.01$), as well as for Lac$_{max}$ (+10.8%, $P < 0.05$) (Table 3). IT also showed a slight, but significant reduction in HR$_{max}$ as compared to pre-intervention (−1.4%, $P < 0.05$). Tendencies for a main effect (intervention × time) were seen for VO_{2max} relative to body mass ($P = 0.09$), absolute PPO ($P = 0.07$), and PPO relative to body mass ($P = 0.10$).

In IT, the inter-individual variation for the change in VO_{2max} was large (1.1–11.2%; Fig. 3). Male subjects improved VO_{2max} more (+7.5%, from 54.2 ± 3.1 to 58.3 ± 2.7 ml kg^{-1} min^{-1}; $P < 0.01$) than females (+2.1%, from 50.4 ± 6.6 to 51.6 ± 6.5 ml kg^{-1} min^{-1}; $P < 0.05$). Excluding the female subjects from the statistical analysis, the male subjects of IT ($N = 9$) improved relative ($P = 0.01$) and absolute ($P = 0.02$) VO_{2max}, absolute PPO ($P = 0.04$) significantly more than the male subjects of CT ($N = 6$).

Submaximal values

VO_2 and power output at VT$_2$ were increased in IT only (+7.4, +9.6%, respectively; $P < 0.01$). These changes were significantly greater than in CT ($P < 0.05$). Post-intervention,

Table 3 Maximal results from the ramp incremental exercise test before and 7 days after training intervention

	IT ($N = 13$)		CT ($N = 8$)	
	Before training	7 days after training	Before training	7 days after training
VO_{2max} (ml min^{-1})	3,497 ± 621	3,676 ± 726**	3,666 ± 654	3,752 ± 672*
VO_{2max} (ml kg^{-1} min^{-1})	53.0 ± 4.6	56.2 ± 5.1**	52.9 ± 6.3	54.4 ± 7.0
PPO (W)	347 ± 67	363 ± 73**	339 ± 63	346 ± 59
PPO (W kg^{-1})	5.3 ± 0.4	5.5 ± 0.5**	4.9 ± 0.5	5.0 ± 0.5
HR$_{max}$ (bpm)	195 ± 6	192 ± 7*	198 ± 8	196 ± 7
RER$_{max}$	1.24 ± 0.04	1.24 ± 0.04	1.20 ± 0.03	1.21 ± 0.04
O$_2$ pulse (ml bpm)	18.0 ± 3.4	19.2 ± 4.1**	18.6 ± 3.6	19.2 ± 3.7*
Lac$_{max}$ (mmol L^{-1})	11.6 ± 2.0	12.9 ± 1.5*	10.5 ± 2.9	11.4 ± 1.3

Parameters are shown as mean ± SD

PPO peak power output, *HR$_{max}$* maximal heart rate, *RER$_{max}$* maximal respiratory exchange ratio, *Lac$_{max}$* maximal blood lactate concentration

* Significant difference compared to before training ($P < 0.05$)

** Significant difference compared to before training ($P < 0.01$)

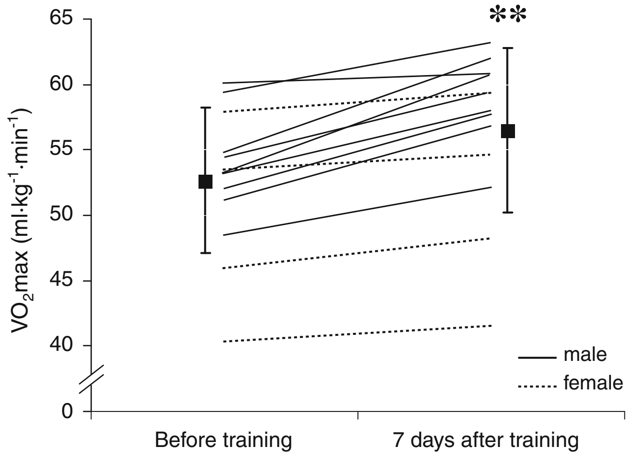

Fig. 3 Inter-individual variability of changes in maximal oxygen consumption ($VO_{2\max}$) with standard *error bars* for male (*continuous line*) and female (*dotted line*) subjects of the high-intensity interval training group

$\%VO_{2\max}$ at VT_2 was significantly higher in IT than CT ($P < 0.05$; Table 4). At VT_1, only IT showed increased VO_2 (+5.8%, $P < 0.01$), whereas the corresponding power output remained unchanged.

tlim and high-box jump performance

tlim and total number of jumps performed after 90 s in the high-box test were not altered by intervention in either group (Table 5). Change in high-box jump performance in IT was significantly different between males and females (+4.9 vs. −1.6%, $P < 0.05$).

Counter movement and squat jump performance

Peak power was significantly reduced post-intervention in IT only (P_CMJ −4.8%; P_SJ −4.1%, $P < 0.01$). Neither IT nor CT showed changes in H_CMJ or H_SJ (Table 6).

Table 4 Submaximal results from the ramp incremental exercise test before and 7 days after training intervention

	IT ($N = 13$)		CT ($N = 8$)	
	Before training	7 days after training	Before training	7 days after training
VT_1_VO_2 (ml min^{-1})	2,018 ± 385	2,135 ± 430**	1,960 ± 351	1,977 ± 397
VT_1_power (W)	142 ± 37	145 ± 38	134 ± 32	135 ± 33
VT_1_$\%VO_{2\max}$	57.8 ± 5.6	58.3 ± 6.3	53.6 ± 3.9	52.6 ± 4.7
VT_1_HR (bpm)	143 ± 8	142 ± 10	142 ± 15	138 ± 10
VT_2_VO_2 (ml min^{-1})	2,981 ± 540	3,203 ± 582**,†	3,089 ± 514	3,097 ± 556
VT_2_power (W)	244 ± 50	268 ± 54**,†	244 ± 45	247 ± 47
VT_2_$\%VO_{2\max}$	85.3 ± 3.9	87.5 ± 4.9†	84.5 ± 3.7	82.7 ± 4.8
VT_2_HR (bpm)	176 ± 6	175 ± 9	176 ± 16	171 ± 13

Parameters are shown as mean ± SD

VT_1 ventilatory threshold 1, *VT_2* ventilatory threshold 2

** Significant difference compared to before training ($P < 0.01$)

† Significant difference between groups ($P < 0.05$)

Table 5 Results from the tlim and high-box tests

	IT			CT		
	Before training	7 days after training	*N*	Before training	7 days after training	*N*
tlim_all (s)	137 ± 20	144 ± 24	13	148 ± 28	168 ± 41	8
tlim_male (s)	133 ± 22	146 ± 22	9			
tlim_female (s)	143 ± 32	153 ± 31	4			
high-box jump_all (jumps)	88 ± 12	90 ± 13	11	86 ± 10	85 ± 12	5
high-box jump_male (jumps)	93 ± 6	97 ± 3*	7			
high-box jump_female (jumps)	79 ± 16	77 ± 14	4			

Parameters are displayed as mean ± SD

tlim time to exhaustion at 90% of pre-intervention peak power output, *high-box jump* number of jumps performed during 90s

* Significant difference compared to before training ($P < 0.05$)

Table 6 Results from the countermovement and squat jump tests before and 7 days after training intervention

	IT ($N = 13$)		CT ($N = 8$)	
	Before training	7 days after training	Before training	7 days after training
CMJ_H (cm)	45.9 ± 7.4	45.8 ± 5.8	44.5 ± 4.1	46.3 ± 3.3
CMJ_P_{max} (W/kg)	51.7 ± 5.5	49.1 ± 5.0**	48.1 ± 4.1	48.5 ± 3.7
SJ_H (cm)	41.7 ± 6.9	41.5 ± 6.3	42.0 ± 4.0	42.2 ± 2.1
SJ_P_{max} (W/kg)	51.1 ± 6.0	49.0 ± 5.6**	48.7 ± 4.1	49.0 ± 3.7

Parameters are shown as mean ± SD

CMJ countermovement jump, *SJ* squat jump, *H* jump height, P_{max} maximal power

** Significant difference compared to before training ($P < 0.01$)

Discussion

The main finding of the present study was that during off-season an 11-day *shock* microcycle consisting of 15 high-intensity interval sessions was able to improve VO_{2max}, PPO and power output at VT_2 in elite junior skiers in a very time-efficient way. A more traditional mixed training regime showed minor changes in only a few parameters over this short time period.

In the present study, we have provided the first primary data on the effectiveness of block training comprising 15 HIT sessions within only 11 days. The 6% improvement in relative VO_{2max} after HIT is in line with the results reported in a short note in Stolen's review on physiology of soccer players (Stolen et al. 2005). In that preliminary study, elite soccer players performed 13 HIT sessions (4 × 4 min protocol) on a dribbling track within 10 days. While the various training interventions used in previous HIT studies are clearly not all equally effective for improving VO_{2max}, 10- to 11-day HIT *shock* microcycles employing 4 × 4-min sessions compare well with the most effective protocols studied elsewhere.

Shorter (0.5 to ~3.5 min), more-intense (100–175% PPO) intervals performed 2–3 times per week over 3–4 weeks have repeatedly produced improvements in VO_{2max} (5.4–8.1%), peak aerobic intensity (4.7–6.2%), and time-trial performance in well-trained cyclists (Gross et al. 2007; Laursen et al. 2002) and runners (Smith et al. 1999) which are comparable to our results. Further, slightly longer and more-intense intervals have been similarly effective for highly trained cyclists (Lindsay et al. 1996; Westgarth-Taylor et al. 1997). Several other studies employing the same 4 × 4-min protocol, but over longer training periods (8–10 weeks) have reported similar improvements in VO_{2max} (Helgerud et al. 2001, 2007; Hoff et al. 2002; McMillan et al. 2005). For example, male youth soccer players (VO_{2max} >58 ml kg^{-1} min^{-1}) improved VO_{2max} by ~10% after performing sessions on a dribbling track twice per week for 8 (Helgerud et al. 2001) or 10 weeks (McMillan et al. 2005); elsewhere, 24 sessions performed over 8 weeks led to 7.2% improvement in VO_{2max} in trained males which was similar to the improvement in our male subjects (Helgerud et al. 2007).

By applying 13 HIT sessions within a 10-day training block, Stolen et al. (2005) reported a mean VO_{2max} improvement of 0.56% per session, which was higher than the 0.43% per session found in the present study. The difference may be due to training mode. Although the soccer players trained on a dribbling track, our subjects performed all, but three HIT sessions on a cycle ergometer. For non-cyclists, local muscle fatigue may present an obstacle to maximally stressing the cardiovascular system while cycling (Martinez et al. 1993). Likewise, heart-rate kinetics during cycling ergometer sessions was slower as compared to the obstacle track sessions (Fig. 2). These observations indicate that during HIT sessions total time spent near VO_{2max}, which is supposed to be critical for training adaptation, would be less in cycling as compared to running.

In his review, Laursen et al. (2002) presented data of VO_{2max} improvements up to 1.0% per session when different HIT protocols with 0.5 to ~3.5-min interval duration were performed 2–3 times the week over 3–8 weeks. This could imply that the high frequency of HIT sessions used by Stolen et al. (2005) and in our study may compromise the efficiency with regard to the maximal capacity for VO_{2max} improvement. This might be due to inadequate recovery time after the training sessions. On the other hand, the difference could be simply due to the differences in session load and training frequency. The high inter-individual variability in VO_{2max} changes from almost zero up to 11% measured in the present study was greater than that reported in other HIT studies (Helgerud et al. 2001; Laursen and Jenkins 2002; Laursen et al. 2002, 2005). This is probably due to greater subject homogeneity in those studies, in terms of gender and VO_{2max}. Unlike Gross et al. (2007), we found no negative correlation between initial fitness level and improvement of VO_{2max}. However, males (+7.5%) improved significantly more than females (+2.1%). In fact, irrespective of genders' experience, the same effects on VO_{2max} after aerobic training (Lewis et al. 1986) or not

(Weber and Schneider 2002) are unclear, although in our case, the difference could have been coincidental due to the small number of female subjects ($N = 4$). It cannot be determined with certainty to what extent different adaptation of the cardiac output, the oxygen extraction rate, the blood volume or in the oxidative enzymes may lead to a gender-specific response to HIT (Lewis et al. 1986; Weber and Schneider 2002). Changed hormonal factors affected by any menstrual cycle phase and thus influence the aerobic capacity could not be found in the presented magnitude (Lebrun et al. 1995; Lebrun and Rumball 2001). Further research is needed to examine the leading mechanism which may eventually control gender-specific adaptations of physiological parameters after HIT according especially to block periodization.

Our HIT intervention also yielded improved VO_2 (+7.4%) and power output (+9.6%) at VT_2. Other studies using a 4 × 4 min protocol over 8 weeks have shown equivocal effects on physiological thresholds. Helgerud et al. (2001) showed improved running speed (+21.6%) and corresponding VO_2 (+15.9%) at the anaerobic threshold in junior soccer players after 8 weeks of HIT, whereas only improved running speed (+8.7%) was reported in moderately trained subjects (Helgerud et al. 2007). Using shorter intervals (0.5 to ~3.5 min) and well-trained male cyclists with higher initial $VO_{2\max}$ (64.5 ml kg^{-1} min^{-1}), Laursen et al. (2005) reported improved VO_2 (+15–24%), but no change in power output at VT_1 and VT_2 after 4 weeks of HIT. Thus, our 11-day *shock* microcycle was at least as effective as longer HIT intervention periods in terms of improvements in VO_2 and power output at VT_2 in trained athletes. Even though test–retest variability of $VO_{2\max}$, measured with the same device, was shown to be 3–6% (Carter and Jeukendrup 2002; Hodges et al. 2005), the fact that $VO_{2\max}$ and PPO point in the same direction and was improved twice as much in IT as compared to CT argue against a simple random measurement error.

For alpine skiers, it is difficult to measure accurately the direct impact of an athletic training intervention on ski-specific performance, either on-snow or under laboratory conditions. To mimic the high-intensity characteristics of competitive alpine skiing, the subjects were asked to perform a time to exhaustion test at 90% PPO on cycle ergometer and a 90-s high-box jump test. Neither tlim nor the number of jumps achieved during the high-box test changed due to the HIT intervention. Smith et al. (1999) observed increased tlim at the velocity associated with $VO_{2\max}$ after HIT. In their study, training intensity during HIT corresponded to testing intensity, whereas in our work, training intensity to elicit 90–95% $HR_{\max}$ was considerably lower (~65% PPO) than the intensity at which tlim was measured (90% PPO). On the other hand, Lindsey et al. (1996) observed increased tlim at 150% PPO, although HIT was performed at a much lower intensity (80% PPO). Although improvements in tlim seem somewhat equivocal, we cannot eliminate the possibility that due to our methodology, in which tlim was tested 4.5 min after exhaustion in the incremental test, positive changes in this first test might have negatively influenced performance in the subsequent tlim test.

In IT, male subjects improved their mean total number of jumps by 4.9% during the 90-s high-box test while the mean for females decreased by 1.6%. This difference was significant between genders ($P < 0.05$) and in line with the gender-specific differences in $VO_{2\max}$ adaptation found for the IT group in this study. Furthermore, $VO_{2\max}$ relative to body weight and the total jumps performed during the high-box test were significantly correlated for the entire cohort ($r = 0.66$; $P < 0.01$). Taken together, these results might indicate that during high-intensity exercise tasks of short duration, the capacity for aerobic energy supply (i.e. $VO_{2\max}$) can be critical for performance. Because races in alpine skiing last between 60 and 120 s, aerobic capacity might, therefore, influence performance during competition.

Despite steadily increasing training power output throughout the HIT *shock* microcycle (+2.0%; $P < 0.05$), subjects were unable to attain as high peak HR in latter compared to initial sessions (%$HR_{\max}$ −1.6%; $P < 0.01$). Likewise, $HR_{\max}$ was suppressed (−3 beats min^{-1}) in post-compared to pre-testing. This observation has been made before, and is supposedly a result of cumulative fatigue (Halson et al. 2002; Zavorsky 2000). Short-term decreases in $HR_{\max}$ (3–15 beats min^{-1}) that have been reported immediately after 2–10 days of intensified training are thought to be related to disturbance in the autonomic nervous system (Halson et al. 2002; Zavorsky 2000). In contrast to our results, however, concurrent declines in endurance performance in those studies provided some justification for reduced $HR_{\max}$ (Coutts et al. 2007; Halson et al. 2002). A certain degree of "overreaching" could also be important for the desired adaptive response, and in light of the positive progression of training intensity and the improvements in $VO_{2\max}$, it is unclear whether such suppression of $HR_{\max}$ influences the training effect. Therefore, it seems important for coaches and athletes to keep in mind the suppression of $HR_{\max}$ during intense training blocks, especially when HR, calculated as a percentage of pre-intervention values, is used to determine training intensity. Furthermore, we observed reduced maximal power in the counter movement and squat jumps in the post-intervention testing. After periods of strenuous exercise training, reduced power during maximal muscle contraction has been shown to be a good indicator of muscular fatigue (Andersson et al. 2008; Welsh et al. 2008). Considering our observations 7 days post-intervention, it could be concluded that muscular fatigue limited the achievement of HR_{max} and the degree of improvement in PPO. Moreover, because HR_{max} returns to normal after adequate recovery time (Halson et al. 2002; Zavorsky 2000), we suppose that a period of more than 7 days could be necessary to allow complete recovery and supercompensation after such a demanding HIT *shock* microcycle. From our results, it cannot be determined to what extend we reached or possibly overreached the limit of tolerable training load using an 11-day HIT *shock* microcycle. In a group of world class alpine skiers, we found 11% improvements in VO_{2max} after performing 8–10 HIT sessions over a 2-week period, which was followed by 2 weeks of low intensity base endurance training (unpublished data). Regarding HIT organized according to block periodization, further investigations should be directed to answer the question: "How much is too much?" and how many HIT sessions are needed to sustain this improvement over throughout the subsequent training periods.

We believe the advantage of a HIT *shock* microcycle to be its massively reduced overall training volume. This makes it possible to fit high-intensity endurance microcycles into a busy training schedule, where other training tasks such as technical on-snow training take priority. Furthermore, the short overall intervention period might also be very motivating, as training goals can be achieved within a very short time period.

In conclusion, this study has shown that 15 HIT sessions performed in an 11-day *shock* microcycle provide a time-efficient method for improving VO_{2max}, PPO, and the power output at VT_2 in junior alpine skiers. Reduced jump performance and maximal heart rate possibly due to muscular fatigue suggest the need for careful planning and extended recovery to ensure maximal effect of such training periods.

Acknowledgments This project was supported by the Swiss Federal Sport Commission (Project-Nr. 08–04) and by the University of Bern, Switzerland. We especially thank Dr. med Roger Steiner for his contribution as medical supervisor throughout the study and Micah Gross for editorial proof-reading of the manuscript.

Conflict of interest statement The authors declare that they have no conflict of interest.

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