

Effects of 12 weeks of block periodization on performance and performance indices in well-trained cyclists

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The purpose of this study was to compare the effects of two different methods of organizing endurance training in trained cyclists during a 12-week preparation period. One group of cyclists performed block periodization (BP; $n = 8$), wherein every fourth week constituted five sessions of high-intensity aerobic training (HIT), followed by 3 weeks of one HIT session. Another group performed a more traditional organization (TRAD; $n = 7$), with 12 weeks of two weekly HIT sessions. The HIT was interspersed with low-intensity training (LIT) so that similar total volumes of both HIT and LIT were performed in the two groups. BP achieved a larger relative improvement in

VO_{2max} than TRAD ($8.8 \pm 5.9\%$ vs $3.7 \pm 2.9\%$, respectively, $P < 0.05$) and a tendency toward larger increase in power output at 2 mmol/L [la^-] ($22 \pm 14\%$ vs $10 \pm 7\%$, respectively, $P = 0.054$). Mean effect size (ES) of the relative improvement in VO_{2max} , power output at 2 mmol/L [la^-], hemoglobin mass, and mean power output during 40-min all-out trial revealed moderate superior effects of BP compared with TRAD training (ES range was 0.62–1.12). The present study suggests that BP of endurance training has superior effects on several endurance and performance indices compared with TRAD.

Both low-intensity training (LIT) and high-intensity aerobic training (HIT) have positive effects on aerobic endurance, measured as maximal oxygen consumption (VO_{2max}) or power output at lactate threshold (Helgerud et al., 2001, 2007; Esteve-Lanao et al., 2005; Ingham et al., 2008), and the improvement depends on the duration, intensity, and frequency of training sessions and of course genetics and training status (Shephard, 1968; Fox et al., 1973; Wenger & Bell, 1986). As the performance level of the endurance athlete increases, it seems necessary to increase the intensity of the aerobic endurance training to obtain further improvements in lactate threshold and VO_{2max} (e.g., Shephard, 1968; Fox et al., 1973; Wenger & Bell, 1986; Midgley et al., 2006). However, a combination of LIT and HIT seems to be necessary to obtain optimal development of endurance performance (Esteve-Lanao et al., 2007; Laursen, 2010; Seiler, 2010). In accordance with this, it has been suggested that endurance athletes should perform 75–80% of the training as LIT and 10–15% as HIT (Seiler & Kjerland, 2006; Seiler, 2010). However, it remains unclear how to organize LIT and HIT in order to achieve optimal training outcome and endurance performance.

The traditional organization (TRAD) of the training has been two weekly HIT sessions interspersed with LIT. Another way of organizing the training is the proposed “block periodization (BP) model,” in which training

periods are divided into shorter periods (1–4 weeks) with the main focus of improving a few specific abilities like maximal oxygen consumption (VO_{2max}) while other abilities are maintained (Breil et al., 2010; Issurin, 2010; Støren et al., 2012). Recently, potential benefits of BP have been theorized (Issurin, 2010). The idea with BP is to provide adequate stimuli to achieve further adaptations in well-trained athletes and that this is not possible with a general focus on many (all) of the abilities important for the performance (Issurin, 2010). To date, very few studies have tested the relative effectiveness of BP training, especially in well-trained endurance athletes.

In a study by Breil et al. (2010), BP was conducted on alpinists with moderate VO_{2max} values, assessing the effect of a HIT block lasting 11 days. Seven days after the HIT block, the alpinists showed improved VO_{2max} , peak power output, and power output at the second ventilatory threshold, while no improvements occurred in the control group (Breil et al., 2010). Unfortunately, the control group continued their normal training, meaning that the block group performed a larger amount of HIT. In another study, using a crossover design, García-Pallarés et al. (2010) concluded that BP was more effective than traditional periodization in improving performance of world-class kayakers. The superiority of BP was found despite the block training period being 10 weeks and 120 training hours shorter than the period of

traditional periodization (García-Pallarés et al., 2010). It should be noted that during BP, there was a larger relative amount of HIT compared with LIT than during traditional periodization (García-Pallarés et al., 2010). This makes it somewhat challenging to determine whether the positive effect was due to the nature of BP or if it was due to the higher concentration of HIT. Although both these studies indicate that BP provides improved training adaptations, it is difficult to tell whether the observed differences were due to the BP *per se* or if they were due to the increased volume of HIT. Interestingly, we have recently compared the effects of 4 weeks of BP with TRAD of the same training and found superior adaptations after 4 weeks of BP (Rønnestad et al., 2012). However, this study lasted only 4 weeks and did not include any direct measurements of performance (Rønnestad et al., 2012).

Consequently, the present study compared the effects of 12 weeks of training organized as BP with TRAD of the training on indices of endurance performance in trained cyclist. The BP was 1 week of five HIT sessions, followed by 3 weeks of one HIT session, while the traditional training included two HIT sessions every week. Both groups performed the same volume of both LIT and HIT. We hypothesized that BP would provide superior effects on the endurance indices VO_{2max} , lactate threshold, work economy, and performance during a 40-min all-out trial compared with traditional periodization.

Methods

Subjects

Eighteen male competitive cyclists volunteered for the study. Based on the peak power output, power to weight ratios, average amount of training hours per week, and years of competitive cycling, the subjects were regarded as well trained (Jeukendrup et al., 2000). The study was performed according to the ethical standards established by the Helsinki Declaration of 1975 and was approved by the local ethical committee at Lillehammer University College. All cyclists signed an informed consent form prior to participation. The cyclists were assigned and matched into two groups, a BP ($n = 9$) group and a traditional periodization (TRAD; $n = 9$) group based on their VO_{2max} (Table 1). One subject in BP and two subjects in TRAD did not complete the study due to illness during the intervention period. Their data have been excluded.

Table 1. Anthropometric data, competitive experience (experience), and maximal oxygen consumption (VO_{2max}) before (pre) the intervention period for the block training group (BP) and traditional training group (TRAD)

	BP ($n = 8$)	TRAD ($n = 7$)
Body mass (kg)	76 ± 7	78 ± 7
Body height (cm)	181 ± 5	182 ± 6
Age (years)	32 ± 7	34 ± 6
Experience (years)	6 ± 4	6 ± 4
VO_{2max} (L/min)	4.7 ± 0.5	4.9 ± 0.5

Values are mean ± SD.
SD, standard deviation.

Experimental design

Physical tests were performed before (preintervention) and after (postintervention) the 12-week intervention period. During 2 months prior to the intervention period, the BP and the TRAD subjects performed 9 ± 3 and 10 ± 3 h/week of LIT, respectively, with no reported HIT sessions. In order to investigate the effects of two different methods of organization in the training *per se*, it was important that the volume of HIT and LIT was similar in the two experimental groups and reflects real training situations. The BP group conducted a 1-week block of five HIT sessions, followed by 3 weeks of one HIT session per week and focused on a high volume of LIT. This 4-week training period was repeated three times to constitute the 12-week intervention period (Fig. 1). The TRAD group conducted two HIT sessions per week throughout the intervention period, interspersed with a relatively high volume of LIT (Fig. 1). Hence, in order to investigate the effect of BP *per se*, the same volume of both HIT (21.8 ± 1.8 sessions and 21.4 ± 1.6 sessions, respectively; range 20–24 sessions in both groups) and LIT was performed in both groups during this 12-week intervention period (Table 2). This is important in order to investigate the effect of BP *per se* and not the distribution between HIT and LIT. Especially the volume of HIT has been suggested to be crucial to training adaptations in well-trained athletes (e.g., Midgley et al., 2006). The number of HIT sessions was based on intervention and descriptive studies on well-trained endurance athletes that frequently report an average of two HIT sessions per week (e.g., Westgarth-Taylor et al., 1997; Stepto et al., 1999; Laursen et al., 2002; Swart et al., 2009; Seiler, 2010). The intervention was completed during the cyclist preparation phase.

Training

All HIT sessions were performed on the cyclists own bike and the LIT consisted primarily of cycling, with some reporting of cross-country skiing (less than 10% of the total individual LIT volume). Training volume and intensity were calculated on the basis of recordings from heart rate (HR) monitors (Polar, Kempele, Finland). The endurance training was divided into three HR zones: (1) 60–82%, (2) 83–87%, and (3) 88–100% of maximal HR. The cyclists themselves were quite free to organize the LIT. They were told that an LIT session should have a duration of minimum 1 h and be performed in HR zone 1. An overview of the distribution of the endurance training in the three intensity zones for both groups is presented in Table 2. The total volume (hours) of endurance training and the distribution of this training within the training zones were similar between groups. There were no significant difference between BP and TRAD in number of performed HIT sessions during the 12-week intervention period (21.8 ± 1.8 and 21.4 ± 1.6 , respectively; range 20–24 in both groups). The reasons to why some cyclists lost HIT sessions were mainly due to the presence of a mild cold or participating in a training camp focusing on a high volume of LIT.

LIT session should have duration of minimum 1 h and be performed in HR zone 1. HIT sessions alternated between 6×5 and 5×6 min with the exercise intensity being in intensity zone 3. Intervals were separated by 2.5- or 3-min recovery, respectively. All cyclists were instructed to perform each HIT session with the aim to produce the highest possible mean power output across intervals. This makes the actual mean power output of each HIT session an indicator of performance level. In order to monitor the power output during HIT sessions, all cyclists were equipped with a PowerTap SL 2.4 (CycleOps, Madison, WI, USA) mounted on the rear wheel. The PowerTap device is a valid and reliable powermeter (Bertucci et al., 2005). Furthermore, in order to quantify how the training weeks affected the perceived well-being in the legs, the cyclists reported their perceived feelings on a 9-point

Block periodization in well-trained cyclists

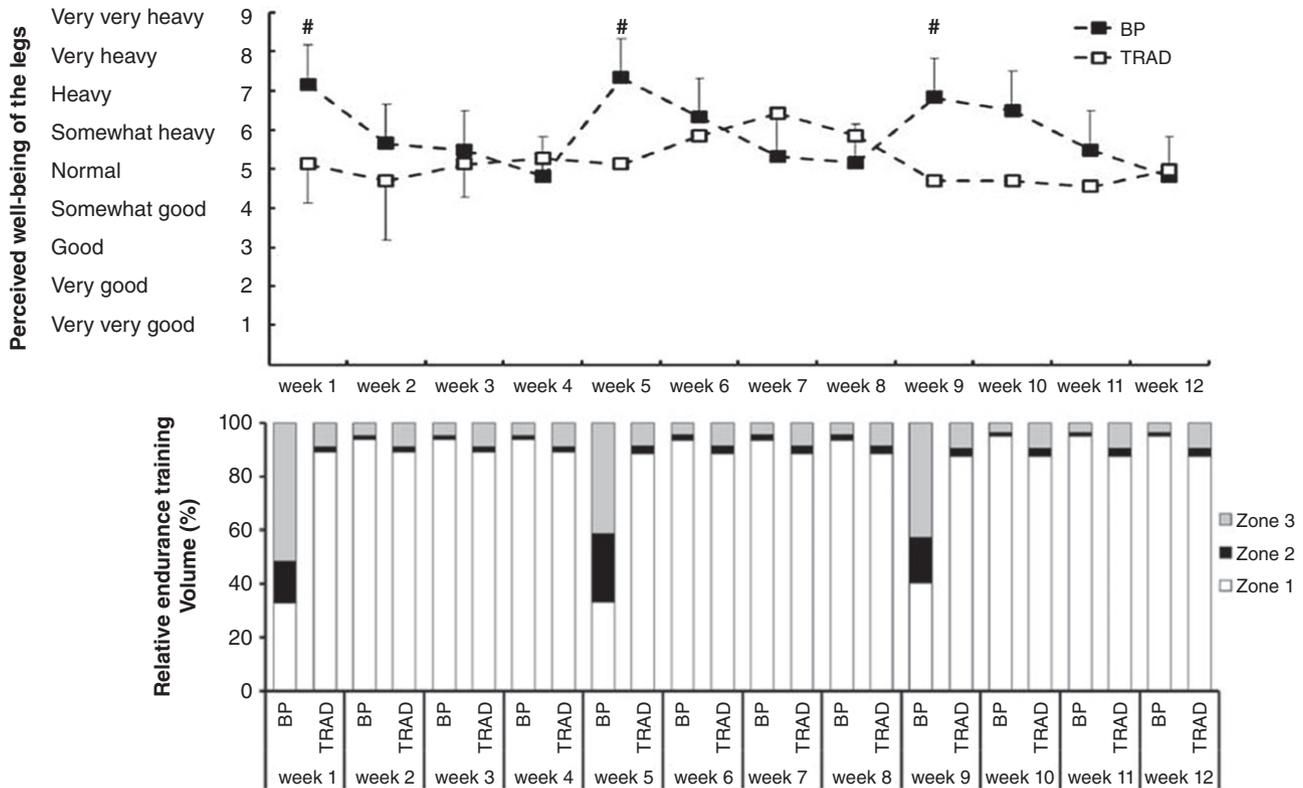


Fig. 1. Weekly relative distribution of training in the different intensity zones during the intervention period for the block periodization (BP) group and the traditional (TRAD) group (lower panel). Perceived feeling of well-being in the legs during the intervention period for BP and TRAD (upper panel). #Difference between groups ($P < 0.05$).

Table 2. Endurance training (in hours per week) during the intervention period divided into three heart rate zones: (a) 60–82%, (b) 83–87%, and (c) 88–100% of maximal heart rate

	BP ($n = 8$)			TRAD ($n = 7$)		
	Weeks 1–4	Weeks 5–8	Weeks 9–12	Weeks 1–4	Weeks 5–8	Weeks 9–12
Intensity zone 1	6.6 ± 3.2	7.1 ± 3.0	8.2 ± 4.3	9.1 ± 3.0	9.6 ± 4.5	7.9 ± 5.1
Intensity zone 2	0.3 ± 0.3	0.6 ± 0.2	0.4 ± 0.1	0.2 ± 0.1	0.3 ± 0.2	0.3 ± 0.3
Intensity zone 3	1.0 ± 0.4	0.9 ± 0.2	0.9 ± 0.2	0.9 ± 0.3	0.9 ± 0.2	1.0 ± 0.5
Other training	1.4 ± 0.5	1.2 ± 0.5	1.1 ± 0.6	0.8 ± 1.0	0.8 ± 1.0	0.4 ± 0.5
Total	9.4 ± 3.2	9.8 ± 2.8	10.5 ± 4.0	11.0 ± 3.2	11.7 ± 5.1	9.6 ± 5.5

Values are mean ± SD.

BP, block periodization; SD, standard deviation; TRAD, traditional organization.

scale, going from *very very good* to *very very heavy* after each training week (Fig. 1).

Testing

On the first test day, an incremental cycle test was performed for determination of blood lactate profile and gross efficiency. After 15 min of recovery, an incremental $\text{VO}_{2\text{max}}$ test was performed and finally Hb_{mass} was determined. On the second test day, the cyclists performed a 40-min all-out trial. This test order was repeated at the posttest. The cyclists were instructed to perform the last HIT session 3 days before the posttest to refrain from all types of intense exercise the day preceding each of the 2 test days and to prepare for the trial as if it was a competition. They were also instructed to consume the same type of meal before each test and were not allowed to eat during the hour preceding a test or to consume coffee or other products containing caffeine during the 3 hours preceding

the tests. All tests were performed under similar environmental conditions (18–20 °C) with a fan ensuring circulating air around the cyclist. Testing at preintervention and postintervention was conducted at the same time of day (± 2 h) to avoid influence of circadian rhythm. All testing was performed on the same electromagnetically braked cycle ergometer (Lode Excalibur Sport, Lode B. V., Groningen, The Netherlands), which was adjusted according to each cyclist's preference for seat height, horizontal distance between tip of seat and bottom bracket, and handlebar position. Identical seating positions were used at pretest and posttest. The subjects were allowed to choose their preferred cadence during all cycling and they used their own shoes and pedals.

Blood lactate profile test

A blood lactate profile was determined for each cyclist by plotting $[\text{la}^-]$ vs power output values obtained during submaximal continu-

ous incremental cycling. The test started without warm-up, with 5-min cycling at 125 W. Cycling continued and power output was increased by 50 W every 5 min. Blood samples were taken from a fingertip at the end of each 5-min bout and were analyzed for whole blood $[la^-]$ using a portable lactate analyzer (Lactate Pro LT-1710, Arcray Inc., Kyoto, Japan). The test was terminated when a $[la^-]$ of 4 mmol/L or higher was reached. VO_2 , respiratory exchange ratio (RER), and HR were measured during the last 2.5 min of each bout, and mean values for this period were used for statistical analysis. HR was measured using a Polar S610i HR monitor (Polar). VO_2 was measured (30-s sampling time) using a computerized metabolic system with mixing chamber (Oxycon Pro, Erich Jaeger, Hoechberg, Germany). The gas analyzers were calibrated with certified calibration gases of known concentrations before every test. The flow turbine (Triple V, Erich Jaeger) was calibrated before every test with a 3-L calibration syringe (5530 series; Hans Rudolph, Kansas, MO, USA). From this continuous incremental cycling test, lactate threshold was set to the power output and VO_2 that corresponded with 2 mmol/L (Rønnestad et al., 2010). Gross efficiency was calculated by using the same method as Coyle et al. (1992). Briefly, rate of energy expenditure was calculated by using gross VO_2 values and their matching RER values, and gross efficiency was expressed as the ratio of work accomplished per minute to caloric expenditure per minute.

VO_{2max} test

After termination of the blood lactate profile test, the cyclists had 15 min of recovery cycling before completing another incremental cycling test for determination of VO_{2max} . This test has been described elsewhere (Rønnestad et al., 2011). Briefly, the test was initiated with 1 min of cycling at a power output corresponding to 3 W/kg (rounded down to the nearest 50 W). Power output was subsequently increased by 25 W every minute until exhaustion. VO_{2max} was calculated as the average of the two highest VO_2 measurements. $HR \geq 95\%$ of known maximal HR, $RER \geq 1.05$, and $[la^-] \geq 8.0$ mmol/L were used as criteria to evaluate if VO_{2max} was obtained. Peak aerobic power output (W_{max}) was calculated as the mean power output during the last 2 min of the incremental VO_{2max} test.

Hemoglobin mass

Hb_{mass} was determined 1 h after the VO_{2max} test by the optimized CO-rebreathing method (Schmidt & Prommer, 2005). Briefly, a pure CO dose (AGA, Lidingö, Sweden) of 90 mL for athletes under 90 kg and 100 mL for athletes over 90 kg was administered and rebreathed for 2 min through a glass spirometer. Capillary blood samples were taken from a fingertip at three time points, prior to and 6 and 8 min after the initial inhalation of CO, and were analyzed for HbCO% using a hemoximeter (OSM 3, Radiometer, Copenhagen, Denmark). Four analyses were done before rebreathing and two at 6 min and two at 8 min. Hb_{mass} was calculated from the mean change in HbCO% as described by Schmidt and Prommer (2008). All calculations were done using the Spico software (Bloodtech, Bayreuth, Germany). The same technician performed all measurements of Hb_{mass} . The typical error of this method in our hands was measured in a separate study to be 1.4%.

Forty-minute all-out trial

The 40-min all-out trial started after a 15-min individual warm-up, which was concluded by two to three submaximal sprints. During the 40-min trial, the cyclists were instructed to cycle at as high average power output as possible. Such closed-end tests have been shown to have a low coefficient of variation (<3.5%; Foss & Hallén, 2005). Performance was measured as the average power

output during the trial. The cyclists were allowed to adjust the power output throughout the trial using an external control unit mounted on the handlebar. The cyclists received no feedback about HR and cadence, but they were aware of remaining time and instantaneous power output. The cyclists were allowed to occasionally stand in the pedals during the trial and to drink water *ad libitum*.

Statistics

All values presented in the text, figures, and tables are mean \pm standard deviation. Effect sizes (ESs) of correlation coefficients were defined as $r < 0.1$ = trivial, $0.1-0.3$ = small, $0.3-0.5$ = moderate, $0.5-0.7$ = large, $0.7-0.9$ = very large, 0.9 = nearly perfect, and 1.0 = perfect (Hopkins et al., 2009). To test for differences between groups at baseline and training volume, unpaired Students *t*-tests were used. The conservative approach of two-way analysis of variance (ANOVA) on the pre-post values showed no differences between groups. Due to the small sample size and expectations of small changes in these already well-trained cyclists, the data were further analyzed with *t*-tests and mean ES. ES was calculated as Cohen's *d* to compare the practical significance of the performance improvements among the two groups. The criteria to interpret the magnitude of the ES were the following: $0.0-0.2$ trivial, $0.2-0.6$ small, $0.6-1.2$ moderate, $1.2-2.0$ large, and >2.0 very large (Hopkins et al., 2009). Pre-intervention to postintervention within group differences were compared using paired Students *t*-test (VO_{2max} , W_{max} , and power output at 2 mmol/L). To test for any differences in relative changes between the groups in VO_{2max} , W_{max} , and power output at 2 mmol/L, unpaired Students *t*-tests were performed. For each group, mean power output during each 4-week period and perceived feeling of well-being in the legs during each week were compared using one-way repeated measures ANOVA. If the ANOVA reached significance, a Tukey's honestly significant difference (HSD) test was performed for post-hoc analysis. To test for differences between groups in changes in mean power output during each 4-week period and subjective feeling of well-being in the legs during each week, two-way repeated measures ANOVA (time and group as factors) with Bonferroni post-hoc tests was performed. *t*-Tests were performed in Excel 2010 (Microsoft Corporation, Redmond, Washington, USA). ANOVA analyses were performed in GraphPad (GraphPad Software Inc., San Diego, California, USA). All analyses resulting in $P \leq 0.05$ were considered statistically significant.

Results

Baseline

There was no significant difference between BP and TRAD before the intervention period with respect to body mass, VO_{2max} , W_{max} , gross efficiency, power output at 2 mmol/L, and 40-min all-out trial (Tables 1 and 2).

Perceived well-being of the legs and mean power output in the HIT sessions

During the weeks with HIT blocks, the perceived well-being in the legs was worse in BP cyclists than in TRAD cyclists ($P < 0.05$; Fig. 1), while there was no difference between the groups during the remaining training weeks (Fig. 1). The mean power of the HIT sessions increased by $4.7 \pm 4.8\%$ and $4.5 \pm 4.2\%$ from weeks 1-4 to weeks 5-8 in BP and TRAD, respectively ($P < 0.05$,

Fig. 2). Only BP increased the mean power output across all HIT sessions from weeks 5–8 to weeks 9–12 ($4.1 \pm 3.4\%$, $P < 0.05$, Fig. 2).

Body mass, W_{max} , and VO_{2max}

Body mass did not change significantly during the intervention in either of the two group (Table 1). W_{max} increased by $6.2 \pm 6.1\%$ in BP ($P < 0.05$) and tended to increase $3.5 \pm 4.5\%$ in TRAD ($P = 0.08$; Table 1). There was no statistically significant difference between groups in relative changes in W_{max} . The relative change in VO_{2max} was greater in BP than in TRAD ($8.8 \pm 5.9\%$ vs $3.7 \pm 2.9\%$, respectively, $P < 0.05$). Mean ES of the relative improvement in W_{max} and VO_{2max} revealed a moderate effect of BP training vs TRAD training (ES = 0.62 and ES = 1.08, respectively).

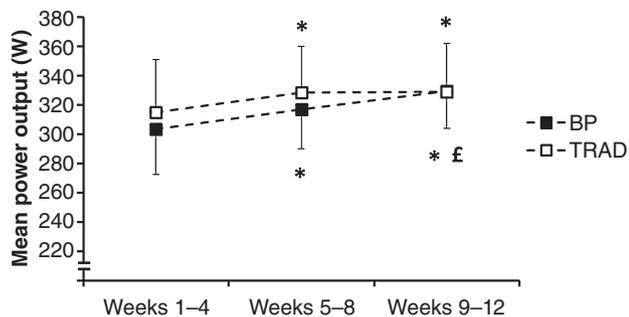


Fig. 2. Mean power output during the high-intensity aerobic training interval sessions across the three 4-week periods for the block periodization (BP) group and the traditional (TRAD) group. *Difference from weeks 1–4 ($P < 0.05$). [‡]Difference from weeks 5–8 ($P < 0.05$).

Hb_{mass}

During the intervention period, there was no significant difference in relative change in Hb_{mass} between BP and TRAD ($5.6 \pm 3.5\%$ vs $1.2 \pm 6.6\%$, respectively, $P = 0.13$). The ES of the relative changes showed a moderate effect of BP training vs TRAD training (ES = 0.83). Across both groups, the relationship between changes in Hb_{mass} and changes in mean power output during the 40-min all-out trial and VO_{2max} was moderate [$r = 0.34$ ($P = 0.24$) and 0.35 ($P = 0.22$), respectively], while it was large for W_{max} ($r = 0.51$, $P = 0.07$).

Power output at 2 mmol/L and gross efficiency

BP tended to show larger relative improvements in power output at 2 mmol/L [la^-] than TRAD ($22 \pm 14\%$ vs $10 \pm 7\%$, respectively, $P = 0.054$, Fig. 3). ES analysis revealed a moderate practical effect of BP training compared with TRAD (ES = 1.12). At posttest, there was a significant difference between BP and TRAD in gross efficiency ($P < 0.01$). The $2.9 \pm 4.1\%$ improvement in gross efficiency in BP was not statistically significant ($P = 0.12$, Table 3), but the ES of the relative improvement gross efficiency revealed a moderate effect of performing BP training vs TRAD training (ES = 1.10).

Power output in the 40-min all-out trial

There was no significant difference in relative improvement in mean power output during the 40-min all-out trial between BP and TRAD ($8.2 \pm 5.7\%$ vs $4.1 \pm 3.1\%$, respectively, $P = 0.12$), but the ES of the relative

Table 3. Data from the performance and physiological tests before (pre) and after (post) the intervention period in the block training group (BP) and the traditional training group (TRAD). The magnitude of improvements of BP vs TRAD is also shown

	BP (n = 8)		TRAD (n = 7)		Magnitude of improvement BP vs TRAD (ES)
	Pre	Post	Pre	Post	
VO_{2max} (L/min)	4.7 ± 0.5	$5.1 \pm 0.6^{*†}$	4.9 ± 0.5	$5.1 \pm 0.6^*$	0.99
(mL/kg/min)	62 ± 2	$68 \pm 5^{*†}$	63 ± 3	$66 \pm 4^*$	1.08
HR_{peak} (beats/min)	187 ± 15	186 ± 15	182 ± 12	179 ± 12	
$[la^-]$ (mmol/L)	13 ± 2	12 ± 3	11 ± 1	12 ± 2	
RPE	19 ± 1	19 ± 1	19 ± 1	19 ± 1	
W_{max} (W/kg)	5.40 ± 0.33	$5.80 \pm 0.43^*$	5.45 ± 0.32	5.67 ± 0.40	0.62
Hemoglobin mass (g)	999 ± 136	$1053 \pm 130^*$	1088 ± 123	1098 ± 120	0.83
$Power_{2mmol/L}$ (W/kg)	2.89 ± 0.50	$3.49 \pm 0.46^{*†}$	3.23 ± 0.43	$3.56 \pm 0.41^*$	1.12
% VO_{2max}	64 ± 9	67 ± 8	68 ± 7	70 ± 7	
Gross efficiency (%)	20.3 ± 0.8	20.9 ± 0.7	19.6 ± 0.4	19.5 ± 0.4	1.10
$Power_{40 min}$ (W/kg)	3.71 ± 0.38	$4.00 \pm 0.31^*$	3.98 ± 0.31	$4.14 \pm 0.30^*$	0.89

Values are mean \pm SD.

*Different from pre ($P < 0.05$).

[†]The relative change from pre is larger than in TRAD ($P < 0.05$).

[‡]The relative change from pre tends to be larger than in TRAD ($P = 0.054$).

VO_{2max} , maximal oxygen consumption; HR_{peak} , peak heart rate; $[la^-]$, blood lactate concentration; RPE, rate of perceived exertion; W_{max} , peak aerobic power output; $Power_{2mmol/L}$, power output at a blood lactate concentration of 2 mmol/L; $Power_{40 min}$, mean power output during 40-min all-out trial; ES, effect size; SD, standard deviation.

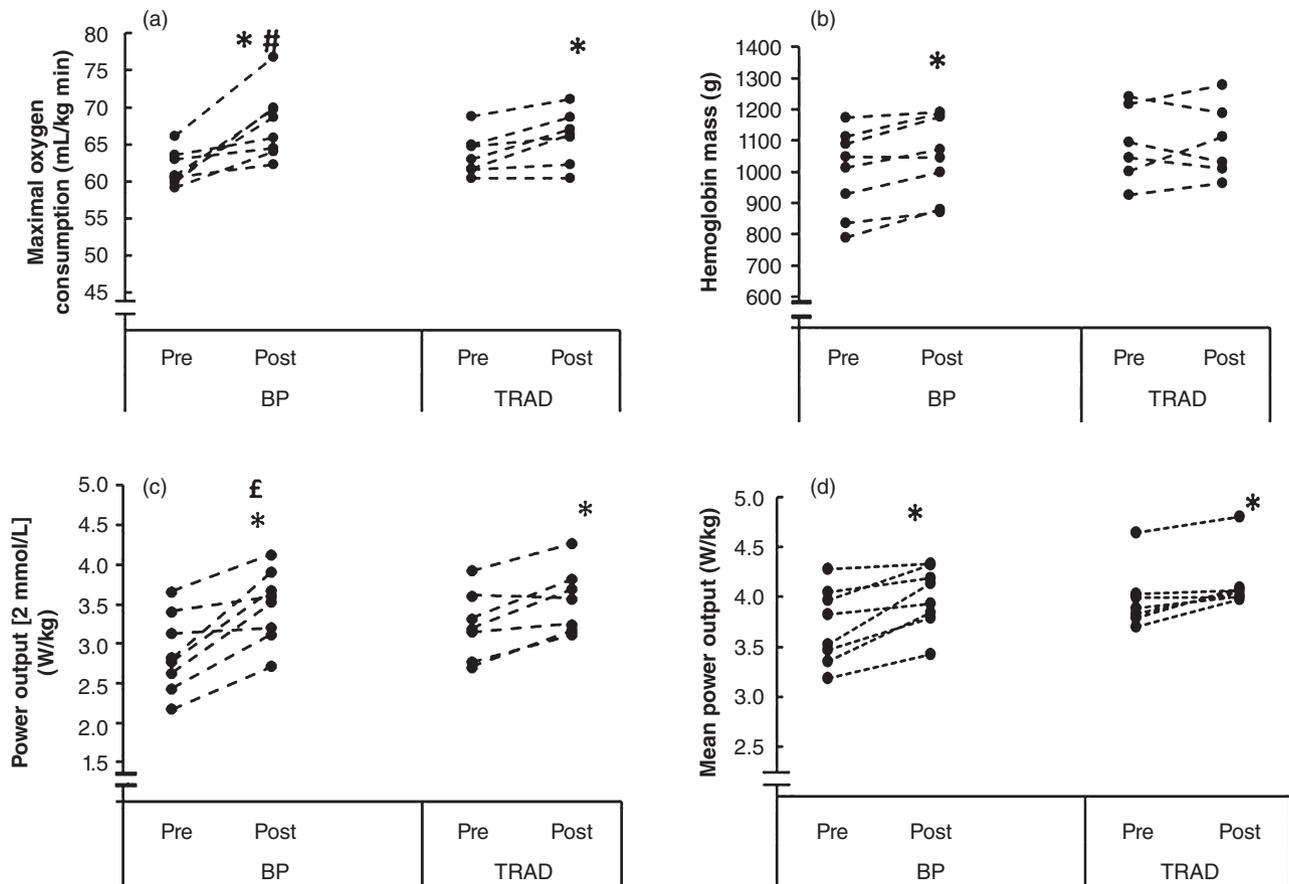


Fig. 3. Individual data points for (a) maximal oxygen consumption, (b) hemoglobin mass, (c) power output (W) at 2 mmol/L [Ia^-], and (d) mean power output during the 40-min all-out trial before (pre) and after (post) the intervention period for the block periodization (BP) group and the traditional (TRAD) group. *Larger than at pre ($P < 0.05$). #The relative change from pre is larger than in TRAD ($P < 0.05$). £The relative change from pre tends to be larger than in TRAD ($P = 0.054$).

improvement revealed a moderate effect of BP training vs TRAD training (ES = 0.89).

Discussion

In the present study, BP of endurance training was found to have superior effects on several endurance and performance indices compared with TRAD. BP cyclists achieved a larger relative increase in VO_{2max} and tended to have larger increase in power output at 2 mmol/L [Ia^-]. Furthermore, the ES of the relative improvement in all measured parameters revealed a moderate effect of BP training vs TRAD training.

VO_{2max}

The effect of BP vs traditional training organizations remains inconclusive. However, the present finding of larger improvement on VO_{2max} in the BP group indicates that BP may be an effective way of organizing the training. This is in line with the increase in VO_{2max} found in response to an 11-day block of HIT in alpinists with moderate VO_{2max} values (Breil et al., 2010). Unfortunately, in the study of Breil et al. (2010), the control

group continued their usual training, resulting in a difference in the total volume of HIT between the two groups. Hence, it is difficult to separate the effect of BP *per se* from that of the difference in HIT volume. Importantly, in the present study, superior VO_{2max} improvement was observed in BP, despite similar volume of high-intensity training and LIT. This larger improvement in the BP group is likely to be partly due to the observed increase in Hb_{mass} in this group, an increase that was not seen in TRAD. The ES of the relative changes in Hb_{mass} showed a moderate effect of performing BP training vs TRAD training (ES = 0.83). The relationship between changes in Hb_{mass} and changes in VO_{2max} across both groups was moderate.

Hb_{mass}

Hb_{mass} is an important determinant of VO_{2max} (Heinicke et al., 2001) and may therefore have impact on endurance performance. It is not clear if endurance training leads to an increase in Hb_{mass} , at least not in previously trained individuals. It has been reported no significant effects of endurance training on Hb_{mass} (e.g., Gore et al., 1997; Prommer et al., 2008). However, the present study indi-

cates that even in endurance-trained individuals, periods with high volume of HIT may increase Hb_{mass} . Importantly, Hb_{mass} has been reported to vary by approximately 3% during a competitive season (Garvican et al., 2010). This was suggested to be partly due to within-season variation in training load (Garvican et al., 2010). Furthermore, moderate trained marathon runners have been reported to show an approximately 4% increase in Hb_{mass} after 3–4 months of combined high-intensity training and LIT (Schmidt & Prommer, 2008). The baseline measurement in the present study was performed following the transition phase, with ~2 months of LIT only. It may thus be suggested that the Hb_{mass} at baseline was lower than the genetically predisposition and thus enable improvement during 12 weeks with intensified endurance training. The change in Hb_{mass} was not significantly different between the two groups, but the ES of the relative changes showed that BP had a moderate positive effect. Unfortunately, the design of the study does not allow us to investigate the mechanism behind this finding.

One potential explanation for the moderate positive effect of BP vs TRAD may be a small expansion in plasma volume after each HIT block (Gillen et al., 1991), with an concomitant up-regulation of the Hb_{mass} to establish the individually normal [Hb] during the following period focusing on LIT (Schmidt & Prommer, 2008). It has also been suggested that circulating growth hormone (GH) may act as a positive stimulus for expansion of plasma volume and erythropoiesis (Christ et al., 1997). As HIT, but not high volumes of LIT, is known to induce a transient increase in circulating levels of GH, partly due to a decrease in blood pH (Wahl et al., 2010), it may be speculated that the frequent transient increases likely to occur during each HIT block may have additive positive effects on Hb_{mass} . Taken together, it might be hypothesized that altering the training pattern *per se* is more important for changes in erythropoietin (EPO) and/or GH secretion than the overall volume of HIT and LIT. To gain further insight into the effect of altered training pattern, Hb_{mass} , plasma volume, GH, and EPO should be measured more frequently and at regular intervals throughout the intervention period.

Forty-minute all-out trial, lactate threshold, and W_{max}

Both BP and TRAD increased performance, measured as body mass-adjusted mean power output during a 40-min all-out trial, by ~8% and ~4%, respectively. This resembles the magnitude of improvements found after less time spanning HIT interventions in well-trained cyclists (2–5%) (Westgarth-Taylor et al., 1997; Stepto et al., 1999; Laursen et al., 2002; Swart et al., 2009). BP tended to give larger improvement in mean power output during the 40-min all-out than TRAD ($P = 0.12$; ES = 0.89, moderate). Furthermore, there was a large correlation between relative changes across groups in mean power output during the 40-min all-out trial and

relative changes in VO_{2max} measured in absolute values ($r = 0.66$). Hence, the tendency towards larger increase in performance after BP is likely to be related to the larger increase in VO_{2max} .

Another contributing factor may be the small, but not significant, improvement in gross efficiency in BP ($P = 0.12$), leading to an ES that revealed a moderate effect of performing BP vs TRAD on this variable (ES = 1.10). It has been suggested that gross efficiency may be improved with HIT (Hopker et al., 2009). Although both groups performed the same volume of HIT in the present study, it might be hypothesized that larger and more concentrated HIT stimulus in the HIT blocks may induce favorable adaptations in well-trained cyclists. The conclusion that BP is superior to TRAD of the HIT is supported by the very large relationship between changes in power output at 2 mmol/L [la^-] and changes in mean power output during the 40-min all-out trial across both groups ($r = 0.86$) and the tendency toward larger relative improvements in power output at 2 mmol/L [la^-] in BP than in TRAD ($P = 0.054$). ES analysis revealed a moderate practical effect of BP training compared with TRAD (ES = 1.12).

It has been shown that W_{max} distinguishes well-trained cyclists from elite cyclists, making it a well-suited predictor of cycling performance (Lucía et al., 1998). The reason for this is probably that W_{max} not only is influenced by VO_{2max} and work economy but also incorporates anaerobic capacity and neuromuscular characteristics (Jones & Carter, 2000). Accordingly, there was a large correlation between relative changes across groups in mean power output during the 40-min all-out performance trial and relative changes in W_{max} in absolute terms ($r = 0.51$). Whereas W_{max} increased by ~6% in BP, it only tended to increase in TRAD (by ~3%, $P = 0.08$). Furthermore, another indication of a beneficial effect on power output performance of BP is the longitudinal change in power output observed during the HIT sessions. While both groups increased their mean power output across all HIT sessions from the first 4-week period to the second 4-week period by ~5%, only BP resulted in significant increases in mean power output (~4%) across all HIT sessions from the second 4-week period to the third and last 4-week period.

Well-being of the legs

The cumulative fatigue of the HIT block is likely to have induced a so-called long-lasting delayed effect (Issurin, 2010), which in turn may have made the athletes adapt to a higher level of performance. Indeed, based on the cyclists' perceived feelings of well-being in their legs, it seems that fatigue was accumulated during the HIT blocks. The cyclists reported that their legs were *heavy* after the HIT blocks, while they returned to normal during the following weeks when focusing on LIT, though still performing one HIT session a week. In

contrast, the TRAD group reported *normal* legs during the entire training period, indicating that the concurrent focus on HIT and LIT provided smaller peaks of training stimulus. It is well known that the better trained the athlete is, the larger stimuli are necessary to achieve further improvements. The larger stimuli of HIT during each HIT block is likely to explain the favorable adaptations to BP. HIT has been suggested to be necessary to improve factors related to the delivery of O₂ to the working muscles during whole body exercise in the well-trained endurance athlete (e.g., Midgley et al., 2006). Furthermore, HIT efficiently activates important signal pathways involved in the mitochondrial biogenesis. Indeed, it has recently been shown exercise intensity-dependent regulation of intracellular signaling cascades that are central in the mitochondrial biogenesis – implying superiority of HIT vs LIT (Egan et al., 2010; Tobina et al., 2011). Lastly, it is known that the most putative stimulus for capillarization in skeletal muscle is increased shear stress (hyperemia) and high strain (e.g., muscle stretch; reviewed in Egginton, 2011). This may indicate that HIT is an efficient stimulus for exercise-induced capillarization. It may therefore, based on these effects of HIT, be hypothesized that the larger and more concentrated HIT stimulus achieved during each HIT block induces the superior adaptations in BP. Further studies should investigate molecular aspects of BP vs TRAD and thus add further understanding of different ways of training organization. The efficacy of BP has also been demonstrated in world-class kayakers (García-Pallarés et al., 2010), in trained cyclists (Rønnestad et al., 2012), and in a single-case study on a well-trained cyclist (Støren et al., 2012).

Summary

The present study indicates that organizing endurance training into a 1-week five HIT session block separated by 3 weeks of one HIT session a week and a general focus on LIT for 12 weeks results in superior adaptations compared with 12 weeks of TRAD with two weekly HIT sessions interspersed with LIT. This was evident from the ES of the relative improvement of VO_{2max}, W_{max},

Hb_{mass}, power output at 2 mmol/L [Ia⁻], and mean power output during 40-min all-out trial, which revealed a moderate effect of BP training vs TRAD training. This superiority of BP was observed despite the total volume and intensity of the training being similar in the two modes of training organization.

Perspectives

It is unclear how to best organize HIT and LIT in order to achieve optimal endurance performance. It has been argued that the traditional way of organizing the training has focused on concurrent development of too many abilities, leading to suboptimal stimulus and thus suboptimal adaptations in the well-trained athlete, whereas this can be avoided by using BP (Issurin, 2010). BP uses short training periods with focus on improving few selected abilities and thus enables a large enough stimulus (Issurin, 2010). The present study supports previous findings of superiority of BP (García-Pallarés et al., 2010; Rønnestad et al., 2012). In the present study, it was 12 weeks of BP organized into three 4-week macrocycles (1 week of five HIT sessions, followed by 3 weeks with focus on LIT with one HIT session per week) compared with traditional training (two HIT sessions every week interspersed with a relatively high volume of LIT throughout the intervention period). The present study indicates that BP results in superior adaptations than more TRAD of the training despite the total volume and intensity of the training are similar. BP of the training may therefore be a good alternative for endurance athletes.

Key words: training organization, endurance performance, lactate threshold, maximal oxygen consumption, peak power output.

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