

## Block periodization of high-intensity aerobic intervals provides superior training effects in trained cyclists

B. R. Rønnestad, J. Hansen, S. Ellefsen

Section for Sport Science, Lillehammer University College, Lillehammer, Norway

Corresponding author: Bent R. Rønnestad, Lillehammer University College, PB. 952, 2604 Lillehammer, Norway. Tel: +47 61288193, Fax: +47 61288200, E-mail: bent.ronnestad@hil.no

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The purpose of this study was to compare the effect of two different methods of organizing endurance training in trained cyclists. One group of cyclists performed block periodization, wherein the first week constituted five sessions of high-intensity aerobic training (HIT), followed by 3 weeks of one weekly HIT session and focus on low-intensity training (LIT) (BP;  $n = 10$ ,  $VO_{2max} = 62 \pm 2$  mL/kg/min). Another group of cyclists performed a more traditional organization, with 4 weeks of two weekly HIT sessions interspersed with LIT (TRAD;  $n = 9$ ,  $VO_{2max} = 63 \pm 2$  mL/kg/min). Similar volumes of both HIT and LIT was performed in the two groups. While BP increased  $VO_{2max}$ , peak power output ( $W_{max}$ )

and power output at 2 mmol/L [ $la^-$ ] by  $4.6 \pm 3.7\%$ ,  $2.1 \pm 2.8\%$ , and  $10 \pm 12\%$ , respectively ( $P < 0.05$ ), no changes occurred in TRAD. BP showed relative improvements in  $VO_{2max}$  compared with TRAD ( $P < 0.05$ ). Mean effect size (ES) of the relative improvement in  $VO_{2max}$ ,  $W_{max}$ , and power output at 2 mmol/L [ $la^-$ ] revealed large to moderate effects of BP training compared with TRAD training (ES = 1.34, ES = 0.85, and ES = 0.71, respectively). The present study suggests that block periodization of training provides superior adaptations to traditional organization during a 4-week endurance training period, despite similar training volume and intensity.

The major physiological determinants for endurance performance are work economy, lactate threshold, and maximal oxygen consumption ( $VO_{2max}$ ; Pate & Kriska, 1984). It is therefore of great interest to assess how these parameters are affected by different endurance training protocols and regimens. To obtain improvements to work economy in trained endurance athletes, it seems to be necessary to perform a high volume of low-intensity training over an extended period of time (Scrimgeour et al., 1986; Lucía et al., 2002). As for improvements in lactate threshold measured as workload at a certain blood lactate concentration ( $[la^-]$ ) and  $VO_{2max}$ , both low-intensity endurance training and high-intensity aerobic training (HIT) have been shown to have a positive effect (Helgerud et al., 2001, 2007; Esteve-Lanao et al., 2005; Ingham et al., 2008). The size of the improvement to these parameters depends on the duration, intensity, and frequency of training sessions (Shephard, 1968; Fox et al., 1973; Wenger & Bell, 1986; Helgerud et al., 2007), in addition to the training status of the athlete. Indeed, a combination of high training volume at low exercise intensities and lower training volumes of HIT seems to be necessary to obtain optimal development of endurance performance (Esteve-Lanao et al., 2007; Laursen, 2010; Seiler, 2010).

As the performance level of the endurance athlete increases, it seems that it is necessary to increase the intensity of the aerobic endurance training to obtain further improvements in lactate threshold and  $VO_{2max}$  (Shephard 1968; Fox et al., 1973; Tanaka et al., 1986; Wenger & Bell, 1986; Yoshida et al., 1990; Midgley et al., 2006). Numerous studies points toward the superiority of HIT, either alone or in combination with low-intensity endurance training, as compared with low-intensity endurance training only (e.g., Billat, 2001; Helgerud et al., 2007; Midgley et al., 2007). In accordance with this, it has been suggested that endurance athletes should perform 75–80% of the training at low intensities, and 10–15% above the second ventilatory threshold (Seiler & Kjerland, 2006; Seiler, 2010), i.e., HIT. Despite this important insight, it remains unclear how to co-organize low-intensity training and HIT in order to achieve optimal training outcome and performance. Recently, focus has been shed on potential benefits of block periodization (Issurin, 2010), wherein shorter training periods (1–4 weeks) are utilized to focus on improving a few selected abilities (Breil et al., 2010; Issurin, 2010; Støren et al., 2011). This has also been described as ‘a training cycle of highly concentrated specialized workloads’ and shock microcycle (reviewed in Issurin, 2010). In this context, traditional organization

of training periods have been argued to focus on developing too many abilities simultaneously, leading to sub-optimal stimulus and thus suboptimal adaptations in well-trained athletes (Issurin, 2010). Conversely, block periodization focus on developing a few selective abilities in each block and thereby ensuring adequate stimuli and adaptations, while at the same time maintaining other abilities important for performance (Issurin, 2010).

By using a crossover design, García-Pallarés et al. (2010) concluded that block periodization was more effective than traditional periodization in improving performance of world-class kayakers. The superiority of block periodization was found despite the training period being 10 weeks and 120 training hours shorter than the period of traditional periodization (García-Pallarés et al., 2010). Accordingly, it seems plausible to assume that block periodization will be superior to traditional training also when the two groups perform similar amounts of endurance training. It should be noted that, because the block periodization period was 10 weeks shorter than the traditional period (12 vs 22 weeks, respectively), the former constituted a larger relative amount of HIT compared with low-intensity training (García-Pallarés et al., 2010). This makes it difficult to determine whether the positive effect of was due to the nature of block periodization or if it was due to the higher concentration of HIT. A second study to investigate the effects of block periodization was conducted on alpinists with moderate  $VO_{2max}$  values, assessing the effect of a HIT block lasting 11 days (Breil et al., 2010). Seven days after the HIT block, the alpinists had improved  $VO_{2max}$ , peak power output, and power output at the ventilatory threshold 2, 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. Overall, although current findings indicate that block periodization provides improved training adaptations, it is difficult to tell whether the observed differences were due to the block periodization *per se*, or if they were due to the increased volume of HIT in the block group. Supporting this, a positive effect of block periodization of HIT was recently reported in a single case study of a cyclist, where HIT blocks resulted in improved  $VO_{2max}$ , power output at lactate threshold and time trial performance (Støren et al., 2011), although with an apparent lack of generalization.

Because of the paucity of studies assessing the effect of block periodization on trained athletes, the present study investigates the effects of a 1-week block of five HIT sessions, followed by a 3-week period of one HIT session per week and a naturally high volume of low-intensity training in trained cyclists. This is compared with a group of cyclists employing the more traditional two HIT sessions per week organization while simultaneously performing a relatively high volume of low-intensity training. Overall, the two groups performed

equal volumes of both HIT and low-intensity training during the 4 weeks of training. We hypothesized that block periodization would induce superior adaptation in  $VO_{2max}$ , power output at 2 mmol/L [ $la^-$ ], and peak power output ( $W_{max}$ ).

## Methods

### Subjects

Twenty-one trained male cyclists volunteered for the study, which was performed according to the ethical standards established by the Helsinki Declaration of 1975 and was approved by The local ethical committee of the Department of Sports Science, Lillehammer University College. All cyclists signed an informed consent form prior to participation. Two of the cyclists did not complete the study because of illness during the intervention period, and their data are excluded. Based on the peak power output, power to weight ratios, average amount of training hours per week, and years of competitive cycling, the subjects could be regarded as well-trained cyclists (Jeukendrup et al., 2000).

### Experimental design

Physical tests were performed before (pre-intervention) and after (post-intervention) the 4-week intervention period. The trained cyclists were assigned and matched into two groups, a block periodization (BP) group and a traditional periodization (TRAD) group, based on their  $VO_{2max}$ . The BP group conducted a one week block of five HIT session, followed by a three week period of one HIT session per week and a naturally high volume of low-intensity training (BP;  $n = 10$ , age  $30 \pm 7$  years, height  $181 \pm 4$  cm, body mass<sub>pre</sub>  $76 \pm 6$  kg, body mass<sub>post</sub>  $76 \pm 6$  kg; Fig. 1). BP subjects had  $6 \pm 4$  years of competitive experience. The self-reported amount of training during the 2 months leading up to the intervention constituted  $9 \pm 3$  h per week of low-intensity endurance training, with no HIT in BP. The TRAD group conducted two HIT sessions per week throughout the intervention period, interspersed with a relatively high volume of low-intensity training (TRAD,  $n = 9$ , age  $32 \pm 6$  years height  $181 \pm 6$  cm, body mass<sub>pre</sub>  $76 \pm 7$  kg, body mass<sub>post</sub>  $76 \pm 7$  kg; Fig. 1). The TRAD group had  $6 \pm 4$  years of competitive experience. The self-reported amount of training during the 2 months leading up to the intervention constituted  $10 \pm 3$  h per week of low-intensity endurance training, with no HIT in TRAD. In order to investigate the effect of block periodization *per se*, the same volume of both HIT and low-intensity training was performed in both groups during this 4-week intervention period. The intervention was completed during the cyclists preparation phase.

### Training

All HIT sessions were performed on the cyclists own bike and the low-intensity training consisted primarily of cycling, though some cross-country skiing was also performed (up to 10% of total low-intensity training volume). Training volume and intensity were calculated on 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. An overview of the distribution of the endurance training into the three intensity zones for both groups is presented in Fig. 1. The total time spent on endurance training and the distribution of this training within the training zones were similar between groups.

HIT sessions alternated between  $6 \times 5$  and  $5 \times 6$  min with the exercise intensity being in intensity zone 3. Intervals were separated by 2.5- or 3-min recovery, respectively. All cyclists were

## Block periodization vs traditional training

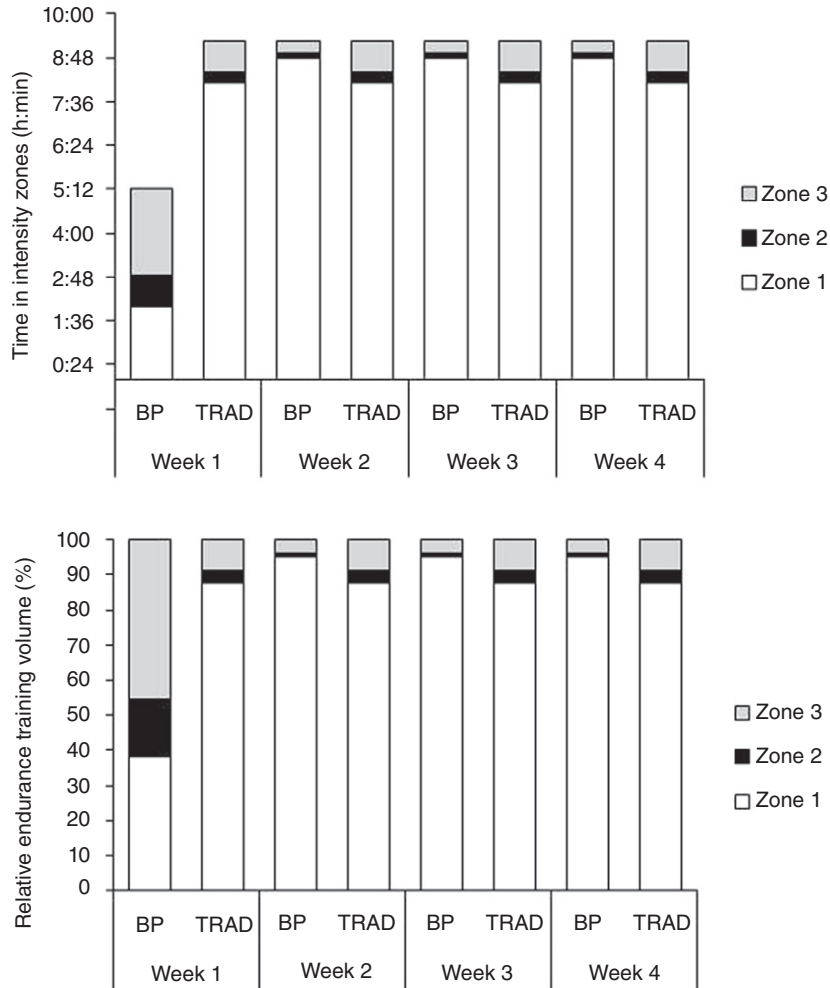


Fig. 1. Weekly distribution of training in the different intensity zones during the intervention period for the block periodization group (BP) and the traditional group (TRAD; upper panel). The relative distribution of the training in the different intensity zones during the intervention period in the two intervention groups (lower panel).

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, seven cyclists in the BP group and six cyclists in the TRAD group 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 power meter (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 scale, going from *very good* to *very very heavy* after each training week (Fig. 2).

### Testing

The cyclists were instructed to refrain from intense exercise 2 days preceding testing and to consume the same type of meal before each test. The cyclists were instructed to perform the last HIT session 3 days before the post-test. They were not allowed to eat during the hour preceding the test or to consume coffee or other products containing caffeine during the preceding 3 h. The cyclists were cooled with a fan during cycling. All tests were performed under similar environmental conditions (20–22 °C). Pre- and post-testing

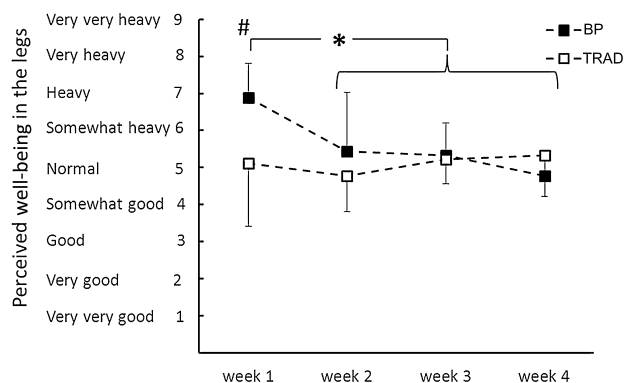


Fig. 2. Perceived well-being in the legs during the intervention period for the block periodization group (BP) and the traditional group (TRAD). \*Difference between the first week and the last 3 weeks in BP ( $P < 0.05$ ). #Difference between groups in the first week ( $P < 0.05$ ).

was conducted at the same time of day to avoid influence of circadian rhythm. All tests were 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 the pre- and post-test. Cyclists 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  $[la^-]$  vs power output values obtained during submaximal continuous 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 measured.  $VO_2$ , respiratory exchange ratio (RER), and HR were measured during the last 3 min of each bout, and mean values were used for statistical analysis. HR was measured using a Polar S610i HR monitor (Polar, Kempele, Finland).  $VO_2$  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, Hoechberg, Germany) was calibrated before every test with a 3-L, 5530 series, calibration syringe (Hans Rudolph, Kansas City, MO, USA). From this continuous incremental cycling test, lactate threshold was calculated as the power output or  $VO_2$  that corresponded with 2 mmol/L (Rønnestad et al., 2010b). Cycling economy was calculated as the average oxygen consumption between 3 and 4.5 min of the first three 5-min submaximal bouts of the blood lactate profile test (125, 175, and 225 W). 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.  $W_{max}$  was calculated as the mean power output during the last 2 min of the incremental  $VO_{2max}$  test. Theoretical maximal aerobic power (MAP) was calculated by using submaximal  $VO_2$  measurements from the blood lactate profile test in addition to the  $VO_{2max}$  values. MAP was defined as the power output where the horizontal line representing  $VO_{2max}$  meets the extrapolated linear regression representing the submaximal  $VO_2$ .

#### Statistics

All values presented in the text, figures, and tables are mean  $\pm$  standard deviation. Mean effect size (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: 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, 2000). To test for differences between groups at baseline and training volume, unpaired Students  $t$ -tests were used (Excel 2010; Microsoft Corporation, Redmond, WA, USA). Pre- and post-intervention measurements for each group were compared using paired Students  $t$ -test. Unpaired Students  $t$ -tests were performed to test for any differences in relative changes between the groups. For each group, mean power output during each HIT session and perceived well-being in the legs during each week, was compared using one-way repeated measures analysis of variance (ANOVA) with Tukey's honestly significant difference test for post-hoc analysis (GraphPad Software Inc, San Diego, CA, USA). To test for differences between groups in changes in mean power output during each HIT session and perceived well-being in the legs during each week, two-way repeated measures ANOVA (time and group as factors) with Bonferroni post-hoc tests were performed to evaluate differences. All analyses resulting in  $P \leq 0.05$  were considered statistically significant.

## Results

### Baseline

There were no significant difference between BP and TRAD before the intervention period with respect to body mass,  $VO_{2max}$ ,  $W_{max}$ , MAP, gross efficiency, cycling economy, and power output at 2 mmol/L.

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

During the first intervention week, the perceived well-being in the legs was lower in BP cyclists than in TRAD cyclists ( $P < 0.01$ ; Fig. 2), while there was no difference between groups throughout the last three intervention weeks (Fig. 2). In accordance with this, BP cyclists reported improved well-being in the legs during the last three intervention weeks compared with the first intervention week ( $P < 0.05$ , Fig. 2). In BP cyclists, the mean power output increased from each of the four first HIT sessions of week 1 to the last HIT session of week 4 ( $7 \pm 5\%$ ,  $6 \pm 6\%$ ,  $7 \pm 5\%$ , and  $7 \pm 5\%$ , respectively;  $P < 0.05$ , Fig. 3), while no statistical significant changes occurred in TRAD.

### Body mass, $W_{max}$ , $VO_{2max}$ , and MAP

The intervention did not alter body mass in either of the two groups. BP resulted in increased  $W_{max}$  and body mass-adjusted  $VO_{2max}$  by  $2.1 \pm 2.8\%$  and  $4.6 \pm 3.7\%$ , respectively (both  $P < 0.05$ , Fig. 4), while no statistical significant changes occurred in TRAD (Fig. 4). Relative changes in  $VO_{2max}$  were greater in BP than in TRAD ( $P < 0.05$ , Fig. 4), while no statistically significant difference were found between groups in relative changes in  $W_{max}$ . Theoretical MAP increased from  $386 \pm 35$  to  $406 \pm 50$  W in BP ( $P = 0.05$ ), while no change occurred in TRAD (pre- and post-intervention values was

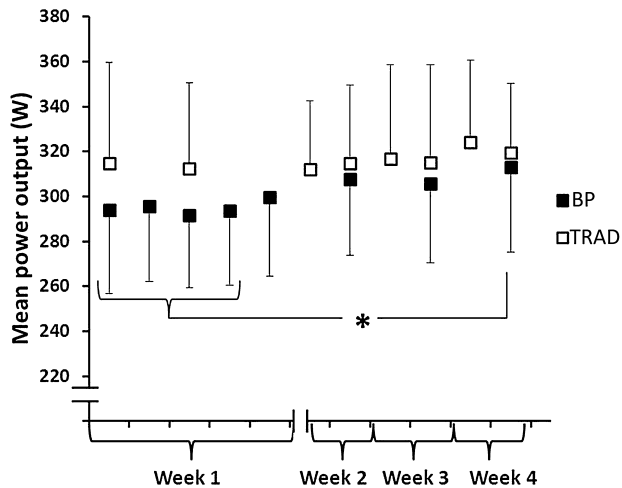


Fig. 3. Mean power output during the high-intensity aerobic training interval sessions during the intervention period for the block periodization group (BP) and the traditional group (TRAD). \*Difference between the four first sessions and the last session in BP ( $P < 0.05$ ).

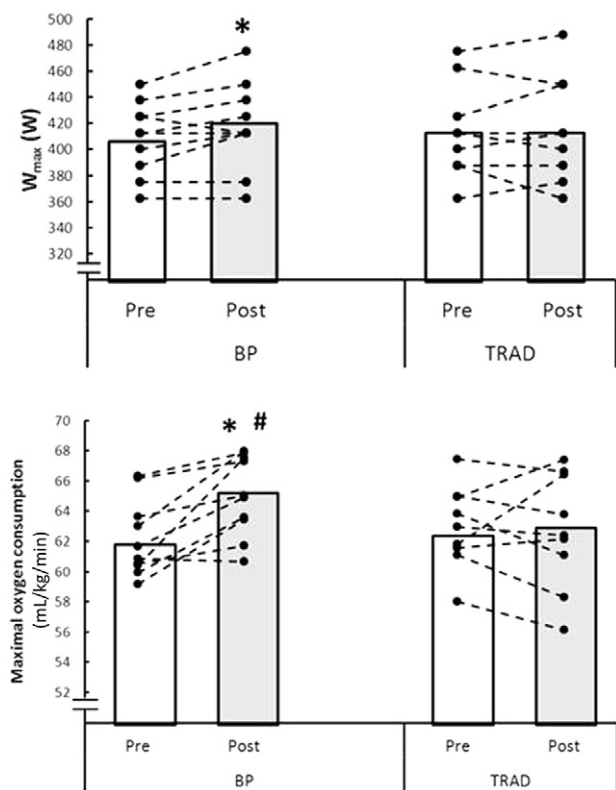


Fig. 4. Maximal oxygen consumption (lower panel) and peak power output ( $W_{max}$ ; upper panel) before (Pre) and after the intervention period (post) for the block periodization group (BP) and the traditional group (TRAD). \*Larger than at Pre ( $P < 0.05$ ), #The relative change from Pre is larger than in TRAD ( $P < 0.05$ ).

## Block periodization vs traditional training

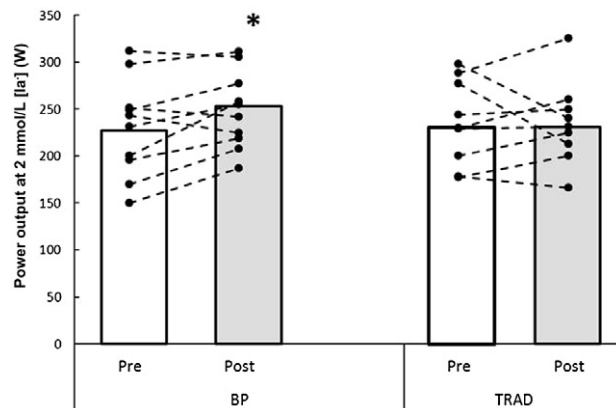


Fig. 5. Power output (W) at 2 mmol/L [ $la^-$ ] before (Pre) and after the intervention period for the block periodization group (BP) and the traditional group (TRAD). \*Larger than at Pre ( $P < 0.05$ ).

382  $\pm$  65 and 377  $\pm$  58 W, respectively). The relative change in MAP was not significantly different between groups. Mean ES of the relative improvement in  $W_{max}$ ,  $VO_{2max}$ , and MAP revealed a moderate to large effect of performing BP training vs TRAD training (ES = 0.85, ES = 1.34, and ES = 1.03, respectively).

### Power output at 2 mmol/L

BP increased power output at 2 mmol/L [ $la^-$ ] by 10  $\pm$  12% ( $P < 0.05$ ), while no change was observed in TRAD (Fig. 5). Although no between-groups difference was evident in relative change in power output at 2 mmol/L [ $la^-$ ], ES analysis revealed a moderate practical effect of BP training compared with TRAD (ES = 0.71). There was no change in fractional utilization of  $VO_{2max}$  at a power output at 2 mmol/L [ $la^-$ ] in either BP or TRAD (pre-intervention values were 64  $\pm$  9% and 66  $\pm$  6%, respectively). There was no difference between groups in neither gross efficiency nor cycling economy, and no change in these measurements was observed in any of the groups during the intervention period. Gross efficiency at a power output of 125, 175, and 225 W was 18.5  $\pm$  1.0%, 20.3  $\pm$  1.0%, and 21.3  $\pm$  1%, respectively, while the cycling economy at these power outputs were 0.209  $\pm$  0.019, 0.189  $\pm$  0.017, and 0.179  $\pm$  0.017 mL/kg/W, respectively, as mean values across groups and time points of intervention.

## Discussion

To the best of our knowledge, this is the first study to compare the effects of block periodization of HIT with those of a more traditional training approach on degrees of training adaptations in endurance-trained athletes using a protocol that provides similar training volumes and intensities. The results suggest that BP induces more

profound ergogenic adaptations in parameters important for endurance performance than TRAD. While BP cyclists increased their  $\text{VO}_{2\text{max}}$ ,  $W_{\text{max}}$ , MAP and power output at 2 mmol/L  $[\text{la}^-]$ , no changes occurred in TRAD. These differences were evident despite the fact that the study protocol investigated the effect of only 4 weeks of training. The present observations are in agreement with previous studies on the topic (Breil et al., 2010; García-Pallarés et al., 2010; Støren et al., 2011).

### $\text{VO}_{2\text{max}}$

The 4.6% increase in  $\text{VO}_{2\text{max}}$  observed in response to BP in the current study is in line with the 6% increase found in response to an 11-day block of HIT described by Breil et al. (2010). Unfortunately, in the study of Breil et al. (2010), the control group continued their usual training resulting in difference in the total volume of HIT between the two groups. This made it difficult to separate the effect of block periodization *per se* from that of the difference in HIT volume. In the present study; however, the number of HIT sessions was identical in the BP and TRAD group, and the ergogenic adaptations found in BP cyclists are thus likely to be due to the organization of the training.

Previous studies on trained cyclists have found intervention periods similar to the TRAD group included in the current study to result in improved  $\text{VO}_{2\text{max}}$ ,  $W_{\text{max}}$ , or time trial performance (3–6-week intervention period with four to eight repetitions of 4–5-min aerobic intervals at 80–85% of  $W_{\text{max}}$ ; Lindsay et al., 1996; Westgarth-Taylor et al., 1997; Stepto et al., 1999). It was therefore somewhat unexpected that the TRAD group failed to show improvements. On the other hand, in a recent study, Nimmerichter et al. (2012) utilized a HIT intervention similar to the one performed by the TRAD group in the present study ( $6 \times 5$  min twice a week during 4 weeks). They also failed to disclose changes in  $\text{VO}_{2\text{max}}$ ,  $W_{\text{max}}$ , or power output at ventilatory threshold (Nimmerichter et al., 2012). In fact, studies lasting 7–8 weeks with two to three HIT sessions ( $4 \times 4$  min) per week have reported change in  $\text{VO}_{2\text{max}}$  (5–7%) similar to those found for the BP group in the present study (Helgerud et al., 2007; Seiler et al. 2011). This could be taken to indicate that longer training intervention periods are needed for the TRAD group to show performance improvements. Interestingly, Nimmerichter et al. (2012) still found improvements in a 20-min outdoor time trial. This indicates that laboratory testing may be less sensitive than outdoor testing on the cyclists' own bike to reveal improvements in athletic performance level. Unfortunately, time trial performance was not measured in the present study. However, laboratory testing has its advantages in terms of a controlled environment. It has been demonstrated that  $W_{\text{max}}$  obtained during a graded exercise test to exhaustion is a

good predictor of outdoor 20 km time trial performance ( $r = 0.91$ ; Hawley & Noakes 1992).

### $W_{\text{max}}$ , MAP and lactate threshold

It has been shown that  $W_{\text{max}}$  distinguishes well-trained cyclists from elite cyclists, something that is not the case for  $\text{VO}_{2\text{max}}$ , making it a well-suited predictor of cycling performance (Lucía et al., 1998). The increase in  $W_{\text{max}}$  and MAP found in response to BP training, but not TRAD training, in the current study is therefore very interesting. It suggests that a performance enhancement took place in BP, but not in TRAD. The improved  $W_{\text{max}}$  in response to BP is in agreement with the observation made by Breil et al. (2010) after an 11-day block of HIT. Further evidence for performance improvement in the BP group is found in the improved power output at 2 mmol/L  $[\text{la}^-]$ . Any rightward movement of the  $[\text{la}^-]$  curve results in improved lactate threshold regardless of how the lactate threshold has been determined (Tokmakidis et al., 1998). An improved lactate threshold theoretically means that an athlete can maintain a higher velocity/power output during a long-term endurance competition. Numerous studies report a strong relationship between long-term performance and lactate thresholds in cycling and it has been demonstrated that such submaximal parameters can be used to predict endurance performance in cyclists with similarly high  $\text{VO}_{2\text{max}}$  (e.g., Bishop et al., 2000; Lucia et al., 2004). Improved performance at lactate threshold has been observed after both long-term HIT (e.g., Helgerud et al., 2001, 2007) and after a short block period of HIT (Breil et al., 2010). Notably, low-intensity training alone has been suggested to be able to increase the speed at lactate threshold in endurance-trained subjects (Ingham et al., 2008). This is unlikely to have affected the results of the current study, as the intervention period was too short to allow for major contributions from the slow mode of adaptation typically displayed by this type of training in trained athletes (Costill et al., 1991).

The present finding of no significant changes in lactate threshold expressed as % of  $\text{VO}_{2\text{max}}$  in the two training groups is in agreement with other studies on endurance-trained athletes (e.g., Sjödin et al., 1982; Helgerud et al., 2001, 2007). Moreover, the finding of a stable gross efficiency is also in accordance with previous observations in cyclists (Impellizzeri & Marcora, 2007; Rønnestad et al., 2010b). However, seasonal changes in gross efficiency are reported (Sassi et al., 2008; Hopker et al., 2009), but not expected during a short training period in trained cyclists. Furthermore, the observation of no change in cycling economy is in line with previous studies (Rønnestad et al., 2010a, 2010b; Aagaard et al., 2011). Because it has been suggested that that high volume of low-endurance intensity training over an extended period of time is necessary to improve the work

economy of endurance athletes (Scrimgeour et al., 1986; Lucia et al., 2002), no improvement was expected during the present 4-week intervention period.

### Well-being in the legs

It has been suggested that that block periodization is more effective than traditional organization of the training (Issurin, 2010). This has been ascribed its focus on developing a few selective abilities in each block, thereby ensuring adequate stimuli and adaptations, while at the same time maintaining other abilities important for performance (Issurin, 2010). In the present study, one block of five HIT sessions resulted in improved  $VO_{2max}$ ,  $W_{max}$ , and lactate threshold in trained cyclists. The cumulative fatigue of the HIT block is likely to have induced a so-called long-lasting delayed effect (Issurin, 2010), which made the athletes adapt to a higher level of performance. Indeed, based on the cyclists' perceived well-being in their legs, it seems that fatigue was cumulated during the HIT block. The cyclists reported that their legs were *heavy* after the HIT block, while they returned to normal during the following weeks when focus was on the low-intensity training, although still performing one HIT session a week. In contrast, TRAD group reported *normal* legs during the entire training period, indicating that the concurrent focus on HIT and low-intensity training provided smaller peaks of training stimulus. Furthermore, whereas the BP group increased the mean power output from each of the four first HIT sessions of week 1 to the last HIT session of week 4, indicating improved performance, the TRAD group did not significantly increase their mean power output in the all-out HIT sessions during the course of the intervention.

### Summary

The present study indicates that organizing endurance training into a 1-week five-session HIT block followed by 3 weeks of one HIT session a week and a general focus on low-intensity training results in superior adaptations compared with 4 weeks of traditional organization with two weekly HIT sessions interspersed with low-intensity training. This was evident from improvements in  $VO_{2max}$ ,  $W_{max}$  and power output at 2 mmol/L [ $la^-$ ] in the BP group, and was underlined by the ES of the relative improvement of these variables, which revealed a large to moderate effect of performing 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. Importantly, the long-term effects of BP remains unknown. The effects of repeating the present 4-week period of BP over a longer period of time remains to be investigated.

### Perspectives

The scientific community seems to agree on the fact that a combination of low-intensity training and HIT is necessary to obtain optimal adaptations for endurance performance (e.g., Seiler & Kjerland, 2006; Laursen, 2010). However, it remains unclear how to best co-organize the two forms of training in well-trained athletes. Traditional training organization has been argued to have a weak spot in its focus on the concurrent development of too many abilities, leading to suboptimal stimulus and suboptimal adaptation (Issurin, 2010). Block periodization has been postulated to avoid this by focusing on a few selected abilities for a short period of time, enabling a larger training stimulus (Issurin, 2010). The present study gives support to the latter postulate by showing that block periodization provides superior effects on parameters important for endurance performance in trained cyclist. In short, a 1-week five-session HIT block followed by 3 weeks of focus on low-intensity training provided superior training adaptations compared with 4 weeks of traditional organization with two weekly HIT sessions interspersed with low-intensity training. This superiority of block periodization is observed despite the fact that the total training volume and intensity was similar between the two modes of organizing the training. It must be noted that although the present study reports evidence for superior adaptation in determinants of performance after block periodization, it remains to investigate the effects on actual cycling performance, such as a time trial.

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

### Conflicts of interest

There is no conflict of interest.

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