Block periodization versus traditional periodization in trained cross-country skiers and biathletes

Vetle Thyli
Abstract

The purpose of this study was to compare the effect of two different methods of organizing endurance training in trained male and female cross-country skiers and biathletes during a 5-week preparation period.

Method

One group of athletes performed block periodization (BP; n=10), wherein week 1 and 3 constituted of respectively five and three sessions of high intensity aerobic training (HIT), followed by respectively one and two weeks of one weekly HIT session. Another group performed a more traditional organization (TRAD; n=9), with four weeks of two HIT sessions and one week of three 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. The majority of the both HIT and LIT were performed on roller skis. All tests were conducted skating on roller ski treadmill.

Results

BP achieved an improvement in maximal oxygen consumption (VO2max), while TRAD did not improve (BP; 2.0 ± 2.5% (p = 0.05), TRAD; –0.1 ± 3.0% (p = 0.75). Also in maximal power output (Wmax) BP achieved an improvement, while TRAD did not improve (BP; 3.8 ± 4.3% (p = 0.016), TRAD; –2.5 ± 6.6% (p = 0.241). Mean effect size (ES) of the relative improvement in VO2max (ES: 0.76) and Wmax (ES: 1.11) revealed moderate superior effects of BP compared to TRAD.

Conclusion

The present study suggests that block periodization of endurance training have superior effects on VO2max and Wmax compared to traditional organization.

Key words: Training organization, Block periodization, Traditional periodization, Endurance performance, Lactate threshold, Maximal oxygen consumption, Maximal power output, Performance VO2, Work economy
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1.0 Theory

Cross-country skiing and biathlon are two sports where endurance is very important for good performance. Endurance can roughly be defined by three physiological determinants; maximal oxygen consumption (VO$_{2\text{max}}$), lactate threshold (LT) and work economy (Losnegard, Myklebust, and Hallen 2012; Ingjer 1991; Ainegren et al. 2012; Bassett and Howley 2000)

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

VO$_{2\text{max}}$ is the highest amount of VO$_2$ the body can absorb, to produce energy to maintain or increase the workload (Bassett and Howley 2000; Losnegard, Myklebust and Hallen 2012; Leclair et al. 2011). VO$_{2\text{max}}$ is therefore one of the most important factors to predict performance in endurance sports, and there is a strong relationship between VO$_{2\text{max}}$ and performance in cross-country skiing (Losnegard, Myklebust, and Hallen 2012; Eisenmann et al. 1989; Aastrand, Rodahl and Dahl 2003; Bosquet, Leger and Legros 2002; Hallen 2004).

The Norwegian Elite Sport Programs (OLT; Olympiatoppen) recommendations of sessions to increase VO$_{2\text{max}}$ are 15 to 30 minutes with VO$_2$ consumption above 87% of VO$_{2\text{max}}$ or heart rate (HR) above 88% of maximum heart rate (HR$_{\text{max}}$) (Olympiatoppen 2012). Studies have shown that interval training has a major influence on VO$_{2\text{max}}$ (Blomquist and Saltin 1983; Astorino 2012). It appears that the relationship between work periods and rest periods in intervals is essential to increase VO$_{2\text{max}}$ for cross-country skiers, and longer work periods are important (Sandbakk et al. 2013), for example 5 minutes working periods with 2 minutes resting periods (Gosselin et al. 2011). It is also important that the intensity is high, and HR above 88% of HR$_{\text{max}}$ has shown great effect (Gosselin et al. 2011; Stoeren et al. 2011; Helgerud et al. 2007; Moffat et al. 1977). High intensity training (HIT) seems to have better effect on both peripheral and central factors affecting VO$_{2\text{max}}$, than low intensity training (LIT) (Daussin et al. 2008).
Fluctuations of workload and oxygen uptake during training performed as HIT sessions, are suggested as key factors to improve muscle oxidative capacities, rather than LIT (ibid.). Skeletal muscle mitochondrial oxidative capacities and maximal output did only increase with HIT, whereas capillary density increased after both trainings (ibid.).

The increase for HIT in central cardiorespiratory adaptions and the peripheral skeletal muscles affected improvement in VO$_{2\text{max}}$, and permitted significant functional improvements (Daussin et al. 2008, Wagner 1991). Top trained athletes will also have to combine HIT and LIT in their training to get required amount of training, because of the longer restitution time with HIT (Seiler, Haugen and Kuffel 2007). The total duration of the HIT sessions is also important, and it has been shown that 32 minutes with 90% of HR$_{\text{max}}$ gives greater response than 16 minutes with 95% of HR$_{\text{max}}$ (Seiler et al. 2011). It is therefore important to find a good combination between training-intensity and -volume, where the duration is long enough, and the intensity is high enough (Storen et al. 2011; Seiler, Olesen and Hetlelid 2011). HIT will demand longer restitution than LIT (Seiler, Haugen and Kuffel 2007), and this explains why the distribution of LIT and HIT among trained endurance athletes is often reported to be 80 and 20%, respectively (Esteve-Lanao et al. 2005; Seiler and Kjerland 2006; Aastrand et al. 2003).

1.2 Lactate threshold
During long endurance competitions for elite long distance runners it is not possible to maintain VO$_{2\text{max}}$ (Billat et al. 1994). An athlete with high LT expressed as % VO$_{2\text{max}}$, will be able to utilize a large percentage of VO$_{2\text{max}}$ without an increase of [La$^-\$] (Bassett and Howley 2000). A high LT, expressed as both % VO$_{2\text{max}}$ and as absolute workload, is described to be a very important factor for performance in cross-country skiing ((Losnegard, Myklebust, and Hallen 2012), Evertsen, Medbo and Bonen 2001). A common definition of LT is 4.0 [La$^-\$] Mmol · l$^{-1}$ (Evertsen, Medbo and Bonen 2001; Knoepfli-Lenzin and Boutellier 2011; Gavin et al. 2012), and we will use power output (watt) at 4.0 Mmol as the LT in our study. When the workload exceeds the LT, [La$^-\$] will increase continuously, and the workload will relatively soon cause exhaustion (Billat et al. 1994; Evertsen, Medbo and Bonen 2001).
To improve the LT, both LIT and HIT has shown positive effect in elite endurance athletes (Helgerud et al. 2001; Helgerud et al. 2007; Seiler, Haugen and Kuffel 2007; Seiler and Kjerland 2006), and the combination of intensity, duration and frequency will determine the size of the improvements (Helgerud et al. 2007; Seiler, Haugen and Kuffel 2007; Seiler and Kjerland 2006). It seems that increased intensity in aerobic endurance training is necessary to give well-trained long distance runners improved LT and VO$_{2\text{max}}$ (Shepard 1968; Midgley, McNaughton and Wilkinson 2006). HIT alone or HIT and LIT combined, gives a bigger development than LIT alone in elite endurance athletes (Helgerud et al. 2007; Seiler, Haugen and Kuffel 2007; Seiler and Kjerland 2006). An improved LT can be caused by an increase of VO$_{2\text{max}}$, and need not to be synonymous with improved work economy. Training with intensity on LT has shown less effect on VO$_{2\text{max}}$ on moderate trained runners, than training with higher intensity during an 8-week training period (Helgerud et al. 2007).

1.3 Work economy

Work economy is defined by the energy cost to move a given distance. Skiing technique and muscular adaptation are therefore two very important factors to develop good work economy (Ainegren et al. 2012; Sunde et al. 2010). Good work economy provides lower energy consumption at a given speed. Improved work economy will lead to better performance in cross country skiing, since the athlete can increase the speed at the same energy consumption (Ainegren et al. 2012). A good measurement for the athletes work economy during activities with exclusively aerobic workload is VO$_2$ per kg bodyweight per meter (Svedenhag 2002). How much of VO$_{2\text{max}}$ an athlete can utilize during long lasting endurance competitions is an important factor to good performance, and can be called the performance VO$_2$ (Bassett and Howley 2000; Coyle 1995). The maximal performance VO$_2$ is reduced with increased competition duration, and well-trained athletes have better performance VO$_2$ than athletes with a poorer training condition (Bassett and Howley 2000; Hallen 2002).
Previous studies on cross country skiers have shown that choice of technique is very crucial for performance, and generally one technique is more energy saving than others, in different terrain types (Kvamme et al. 2005; Gregoire, Boissiere and Candau 2003).

Boulay, Rundwell and King (1995) did a study on skating uphill, which showed that V1\(^1\) gave a better work economy than V2\(^2\), in terrain steeper than 8 %. However, the aforementioned study is old, and Losnegard, Myklebust and Hallen (2012) have shown that there are no difference in VO\(_{2}\text{max}\), O\(_2\)-cost or performance between V1 and V2 in moderate to steep inclines. Its natural to think that the development over the last 20 years in cross-country skiing changed technique abilities, and technique improvements have occurred parallel to the development of sprint skiing and mass starts abilities (ibid.). Muscular endurance and maximal power can also affect the energy costs at different intensities in both elite runners and cyclists (Sunde et al. 2010; Hayes, French and Thomas 2011), and maximal power training can therefore in theory improve work economy in elite distance runners (Paavolainen et al. 1999). Foster et al. (1995) did a study on distance runners, which showed that specific training can improve work economy, through increase of velocity associated with a [La\(^-\)] of 4 Mmol · l\(^{-1}\). It appears that marathon runners and world-class cyclists need to perform a high volume of low-intensity training, to obtain improvements in work economy (Scrimgeour et al. 1986; Lucia et al. 2002).

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1 Technique in cross-country skiing and roller skis which is used in steep uphill skating (figure 3 and 4)
2 Technique in cross-country skiing and roller skis which is used in level terrain and gradual uphill
1.4 Block periodization

Well-trained athletes must systematize their total endurance training in order to optimize their performance and training outcome. There are many theories about how to organize training, and more research is needed in this area. It has recently been focused on shorter training periods (1 – 4 weeks) with focus on improving a few selected abilities (Issurin 2010; Storen et al. 2011). Prioritizing training of a few abilities may give larger training effects, as opposed to focusing on a wider range of abilities (Issurin 2010).

Periodization is a term in sports and sport science to describe programs taking the form of predetermined sequential chains of specifically focused training periods (Kiely 2012). To establish systematic training periods to maximize the total training effect it is important that different fitness adaptations are best developed in a sequential hierarchy, for example endurance before speed. The time frames and periodization cycles should therefore be carefully systematized (ibid.). Block periodization (BP) is a relative new training philosophy, and knowledge and theory in the field is lacking. BP is described as specialized mesocycle-blocks, with highly concentrated training workloads focusing on few physical and technical abilities over a short period, between two to eight weeks. Traditional periodization (TRAD) on the other hand, usually tries to develop many abilities simultaneously (Issurin 2008).

A review from 2008 shows us the increased focus on BP over the last few decades, and it discusses the limitations and drawbacks of TRAD regarding the demands to top-level athletes (ibid.). Sport and sports science have experienced tremendous changes in the BP concept, and there are still a lot of questions regarding how HIT sessions can be organized to maximize performance furthermore (Issurin 2010). The traditional training periodization has remained at more or less the same level, and the concept may not have any further development potential (ibid.).
The failure to provide multiple peak performances during a season and the drawbacks of long lasting mixed training programs can explain the possible lower training adaptations with traditional periodization versus block periodization (Issurin 2008). The negative interactions between non-compatible workloads that induce conflicting training responses, and the insufficient training stimuli to help highly qualified athletes to progress because of mixed training, are suggested as the limitations of TRAD (ibid.). The attempts to overcome these limitations led to development of alternative periodization concepts, and the BP concept tries to minimize these limitations (Issurin 2010). Most studies done on mesocycle-blocks conclude that BP training provides statistic superior performance improvements when compared with constant repetition-programs (Kiely 2012).

It is important to notice that most of these studies have compared the experimental groups to groups with minimal, or no, variation. These studies have more or less only demonstrated that variation is an important aspect of effective training. It has therefore been suggested that the evidence supports the need for regular training variation, and have neither supported nor refuted other core tenets of periodization philosophy (ibid.). Evidence suggests that variation is a necessary component of effective training planning, and that monotony training perceived as a lack of variation leads to increased incidence of overtraining syndromes, poor performance, and frequency of minor infections (ibid.). However, it is also important to be aware that variety in the training can lead to slower progression. If stimuli are excessively varied, and the adaptive energy is too thinly dispersed among multiple training targets, the training progress can be very slow, or non-existent (ibid.). Periodic reduction in variation, will concentrate focus on narrow band of training targets, and can induce rapid development of these prioritized abilities (ibid.). The dynamic balance between the variation and the concentrated focus is important to progress already well developed fitness abilities, the variation can not be to extreme, and the concentrated focus can not be to monotonic (ibid.). It is important to emphasize that the TRAD group in this study has variation in number of HIT sessions each week (i.e. 2-2-3-2-2, Figure 1).
Our criticism and scepticism to previous relevant studies (García-Pallarés et al. 2010; Breil et al. 2010; Ronnestad, Hansen and Ellefsen 2012; Ronnestad et al. 2012) is the lack of variation and differences in the methodology in some of the studies, which may have influenced the results. We want to be confident that our TRAD group got equal amount of stimulus, regarding HIT sessions, and appropriate variation in the intervention period. It has been concluded that BP improved performance in world-class kayakers more than TRAD (García-Pallarés et al. 2010). In the aforementioned study the BP group had shorter intervention period than the TRAD group, and this may have caused an effect on the result (Ronnestad, Hansen og Ellefsen 2012). Another study, on alpine skiers with moderate VO$_{2\text{max}}$, also concluded that BP improved VO$_{2\text{max}}$, peak power output and LT more than TRAD (Breil et al. 2010). The study gave the BP group a larger amount of HIT sessions, which may have influenced results (Ronnestad, Hansen and Ellefsen 2012).

A recent study on well-trained cyclists, showed that a 4-week intervention period with one HIT-block of 5 HIT sessions followed by 3 weeks of 1 HIT session per week, improved VO$_{2\text{max}}$, peak power output and LT more than TRAD (Ronnestad, Hansen and Ellefsen 2012). The TRAD group conducted 2 HIT sessions per week and a similar amount both HIT and LIT in the intervention period. The HIT sessions consisted of both 6 x 5 min and 5 x 6 min intervals. It is suggested that BP provides superior adaptation compared with TRAD during a 4-week endurance-training period, despite similar training volume and intensity (ibid.). The aforementioned study did not have a performance test, and the intervention period only consisted of one HIT-block. The same year the authors performed a very similar study, but with three HIT-blocks over a 12 week long period. Trained cyclists performed every 4th week a HIT-block with five HIT sessions, followed by three weeks of one HIT session. The TRAD-group did two HIT sessions every week (Ronnestad et al. 2012). It was also added a 40-min performance test, other than that the two aforementioned study designs were similar. The BP-group achieved a larger relative improvement in VO$_{2\text{max}}$ than the TRAD-group, and a tendency to larger increases in LT (ibid.). The BP-group also had moderate superior effects of BP compared to TRAD in VO$_{2\text{max}}$, LT and mean power output on performance test, as mean effect size (ES) of the relative improvements (ibid.). The study suggests that BP of endurance training has superior effects on several endurance and performance indices compared to TRAD (ibid.).
In the present study, we want to investigate the effect of BP on cross-country skiers and biathletes during the first phase of the competition phase. We did this because their performance level is at the highest in this period. Many studies have their intervention period in the athletes’ recovery period, where they have greater customization potential, and we didn’t want this to be an issue.

There is little knowledge about BP in endurance sports, but there has been an increased focus during the last few years. Most of the few studies done in this field had deficiencies in their method, both different lengths on the intervention period and different amount of HIT between groups. This might have influenced the results. There are no studies, to our knowledge, done on cross-country skiers and biathletes in this specific field. Several of the relevant studies have not performed more than one HIT-block during the intervention period.

Therefore, we want to investigate how BP affects endurance performance. In addition to test VO$_{2\text{max}}$ and LT, which has been used in previous studies (Ronnestad, Hansen and Ellefsen 2012), we want to add a performance test. This will investigate how BP affects both performance determining factors and performance relative to TRAD.
1.5 Aims and objectives

The aim of this study is to give top athletes applicable knowledge of how to best perform periodization of training to improve performance.

Research question:
Does two-block periodization of high intensity endurance interval training, improve VO_{2max}, LT, work economy and performance more than a traditional periodization model with a total equal volume of high intensity endurance training over a 5-week intervention period?

1.6 Hypotheses

I: 5 weeks of block periodization leads to improved VO_{2max} and maximal power output, compared to traditional periodization, when total duration of HIT and LIT is equal.

II: 5 weeks of block periodization leads to improved LT, compared to traditional periodization, when total duration of HIT and LIT is equal.

III: 5 weeks of block periodization leads to improved performance, compared to traditional periodization, when total duration of HIT and LIT is equal.
2.0 Method

2.1 Subjects
16 male and 5 female trained cross-country skiers and biathletes volunteered for the study (Table 1). All athletes signed an informed consent for participation in the project.

Throughout the intervention period, three athletes dropped out, due to illness. 19 participants completed the study. Joar Hansen, Daniel Buck, Timo Bakken and I conducted the testing, at Lillehammer University College Test lab.

The participants in the project were at a top trained pre intervention, which might be important to see differences between BP and TRAD. Their performance level where controlled by collecting their top results in cross country skiing and biathlon the last two years. The best athletes in both groups have top results (top 3) in national races in Norway, and the weakest results in both groups were top 30 in Norwegian national races. The endurance performance factors have limitations, and it is therefore difficult to improve further when performance and training are at a high level (Bassett and Howley 2000; Amann 2012). Gradually, the development of VO$_{2\text{max}}$, LT and work economy will stagnate (Sandbakk et al. 2010; Karp 2007; Billat et al. 2001). Therefore, it is important for us that the participants are top trained athletes, to investigate if BP minimize these limitations and is more effective than TRAD.
2.2 Experimental design

Physical tests were performed before (pre-intervention) and after (post-intervention) a 5-week intervention period. The participants were randomized into two experimental groups, a block periodization group (BP) and a traditional periodization group (TRAD). There were no differences between the two groups after the randomization (Table 1). Both group conducted the same amount of HIT during the intervention period. The difference was the periodization of the HIT sessions.

**Table 1: Description of groups pre-intervention**

<table>
<thead>
<tr>
<th></th>
<th>BP</th>
<th>TRAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>♂ = 7, ♂ = 3</td>
<td>♂ = 7, ♂ = 2</td>
</tr>
<tr>
<td>Age (Year)</td>
<td>23 ± 9</td>
<td>22 ± 5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179 ± 16</td>
<td>182 ± 9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71 ± 15</td>
<td>74 ± 6</td>
</tr>
<tr>
<td>VO₂max (ml · kg⁻¹ · min⁻¹)</td>
<td>65 ± 6</td>
<td>64 ± 8</td>
</tr>
</tbody>
</table>

Previous training:

<table>
<thead>
<tr>
<th></th>
<th>BP</th>
<th>TRAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last year (hours)</td>
<td>589 ± 166</td>
<td>578 ± 90</td>
</tr>
<tr>
<td>Last month (hours)</td>
<td>58 ± 7</td>
<td>65 ± 14</td>
</tr>
<tr>
<td>HIT per week (hours)</td>
<td>1.2 ± 0.2</td>
<td>1.0 ± 0.1</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation

The BP group performed two weeks of HIT blocks containing 5 and 3 HIT sessions during the intervention period (in week 1 and 3 of the intervention period). In week 2, 4 and 5 they only performed 1 HIT session per week (Figure 1 and 2). The TRAD group conducted the same number of HIT sessions as the BP group, throughout the intervention period, but with another organization. The amount of HIT sessions per week for the TRAD group was 3 in one week (training week 3) and 2 in the remaining 4 weeks (Figure 1 and 2). The intervention period was completed within the last two months of the preparation phase for most of the participants.
**Figure 1:** Illustration of time schedule of pre-tests, intervention period and post-tests, and HIT blocks and HIT sessions each week for the BP group and the TRAD group.

**Figure 2:** Weekly relative distribution of training in the different intensity zones during the intervention period for the block periodization group (BP) and the traditional periodization group (TRAD).
2.3 Training

Most HIT sessions took place in skating on either roller skis or cross-country skis. We focused on getting good and competent active cross-country skiers and biathletes participating in this project, and we didn’t therefore demand every HIT session in skating. Because of the short time to competition period, and to get enough qualified athletes to participate, some of the HIT sessions were performed on classic roller skis and cross-country skis. The BP group conducted 68 ± 20% of the HIT sessions skating, while the TRAD group conducted 68 ± 19% skating with no significant difference between groups (p=0.994). The athletes in both BP and TRAD reported that the HIT sessions on cross-country skis were conducted with required intensity (0.5 ± 0.3 and 0.9 ± 0.3 average hours 14-15 per week, respectively) in the two last weeks of the intervention period due to winter conditions, and did therefore not affect the training outcome. This was controlled with heart rate monitors. There weren’t any requirements regarding terrain type during the HIT sessions, because of the short time prior to the competition period. It is also known that HIT sessions in level terrain also improve endurance (Sandbakk, Welde and Holmberg 2011).

Athletes were instructed to alternate the HIT sessions between 5 x 6 min and 6 x 5 min with the exercise intensity in HR zone 4 and 5. These intervals mixed together in the training program have shown great effect, on both VO$_{2\text{max}}$ and LT (Issurin 2010). Respectively 3 and 2.5 min recovery separated the intervals.

<table>
<thead>
<tr>
<th>Intensity zone</th>
<th>% Of VO$_{2\text{max}}$</th>
<th>% Of HR$_{\text{max}}$</th>
<th>[La$^-$] Mmol · 1$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR zone 5</td>
<td>94 – 100</td>
<td>92 – 97</td>
<td>6,0 – 10,0</td>
</tr>
<tr>
<td>HR zone 4</td>
<td>87 – 94</td>
<td>87 – 92</td>
<td>4,0 – 6,0</td>
</tr>
<tr>
<td>HR zone 3</td>
<td>80 – 87</td>
<td>82 – 87</td>
<td>2,5 – 4,0</td>
</tr>
<tr>
<td>HR zone 2</td>
<td>65 – 80</td>
<td>72 – 82</td>
<td>1,5 – 2,5</td>
</tr>
<tr>
<td>HR zone 1</td>
<td>45 – 65</td>
<td>60 – 72</td>
<td>0,8 – 1,5</td>
</tr>
</tbody>
</table>
The main part of each HIT session was conducted in HR zone 4 and 5, according to the OLT, Olympiatoppen scale (above 87% of HR\(_{\text{max}}\), Table 2). The athletes were instructed to try to start every HIT session in HR zone 4 and end the session in HR zone 5, and not the other way around. The BP group conducted 96 ± 6% of the planned training in HR zone 4 – 5, while the TRAD group conducted 92 ± 7%, with no significant difference between groups (p=0.388).

The participants were also recommended to allocate the HIT sessions like this:

The BP:
- The high intensity week: equal recovery period between each HIT session
- The low intensity week: HIT session in the middle of the week

The TRAD:
- Equal recovery period between each HIT session

The HIT sessions were conducted mostly in uphill conditions. The tests were conducted uphill, and we therefore wanted to eliminate possible increase on the tests because of technique, and focus on increased physical performance. The HIT sessions were conducted with a preferred warm up and warm down exercise.

The LIT consisted of traditional Norwegian endurance training, primarily within classic style and skating on roller skis and cross-country skis, plus a low amount of running. Participants used the OLT; Olympiatoppen scale for endurance training to control their training (Olympiatoppen 2012) (Table 2). Athletes registered their training, mostly via the online journal on www.olt-dagbok.net. We collected training data from the last year, last month and during the training period.
We are relatively safe that the athletes’ journals are of high quality, since they are at such a high level that they wrote journals regardless of their participation in the project. We consider the validity in relation to the registration of the training to relatively solid. It is of course each athlete's responsibility to do this correctly, but this was our best option, and we chose to rely on the registration of the training was of the same quality as their performance level. We consider this method of the registration of the training to be reliable, since the registration is done in the same way as all other top athletes training registration in these types of endurance sports, and more or less the only way to reflect an endurance athlete's training regarding intensity and duration.

Athletes were not allowed to have workouts in HR zone 3. There were no demands regarding the training in HR zone 1 – 2, strength, agility, speed, and stretching (other training). The endurance training was equal in both groups (Table 3).

**Table 3:** Conducted training from the intervention period, as hours in each intensity zone (mean per week ± standard deviation).

<table>
<thead>
<tr>
<th></th>
<th>HR zone 1 – 2</th>
<th>HR zone 3</th>
<th>HR zone 4 – 5</th>
<th>Other training</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCK</td>
<td>10 ± 2</td>
<td>0.1 ± 0.2</td>
<td>1.2 ± 0.2</td>
<td>1.5 ± 0.4</td>
<td>13 ± 2</td>
</tr>
<tr>
<td>TRAD</td>
<td>11 ± 2</td>
<td>0.2 ± 0.2</td>
<td>1.0 ± 0.1</td>
<td>0.9 ± 0.6</td>
<td>13 ± 2</td>
</tr>
</tbody>
</table>
2.4 Testing

Testing was conducted as follows:
Day 1: Blood lactate profile test and VO\textsubscript{2max} test
Day 2: 20 min performance test

Athletes were instructed to avoid high intensity training 2 days before testing, have approximately equal training before pre- and post-tests, and to have the same diet before each test. After the last HIT session athletes were instructed to wait at least 3 days until post-test. Eating was not allowed the last hour before each test, and it was not allowed to consume coffee or other caffeinated products the preceding 3 hours. All tests were performed in the same laboratory, under similar environmental conditions (18 – 21 °C).

All tests were also performed on the same treadmill (Lode Valiant Special, Lode B.V. Groningen, Netherlands), with the same roller skis (Swenor Skate 65-000 type-1 wheels, Sport Import AS. Sarpsborg, Norway) and the same poles (SWIX CT3, Swix Sport AS. Lillehammer, Norway). We followed the standardized tests procedures that are used in Lillehammer University College laboratory regarding speed and inclines on all tests, including warm up.

Pre- and post-testing was performed at the same time of the day (± 1 hour) for each athlete, to avoid influence of circadian rhythm. The athletes could freely choose technique during all tests, because we saw this as more natural, and it has been observed that this will not affect the results (Losnegard, Myklebust and Hallen 2012). Test days 1 and 2 were conducted with a minimum of 48 hours apart, and a maximum of 7 days.

We followed these procedures for every athlete before, during and after each test, and we strived to make all preparations equal for each athlete. We will therefore consider the preparation to each test to be reliable.
2.4.1 Blood lactate profile test

We determined a blood lactate profile for each athlete by measuring [La−] during an incremental exercise test on roller ski skating (Figure 3). Athletes got a 15 minutes warm up before the test began, with following speed and incline:

Men: 13.0 km/h – 3%
Woman: 11.0 km/h – 2%

Figure 3: Illustration photo of athlete during blood lactate profile test, on roller ski treadmill with roller skis and poles, in Lillehammer University College.
The test started with 5 minutes roller skiing on 10.8 km/h (women: 9.0 km/h) and 5% inclination. Blood samples were taken from a fingertip after each 5 min trial, and blood was analysed for whole blood [La'] using the laboratory lactate analyser (Biosen C-line, EKF Diagnostics, Barleben, Germany). The speed was constant while the inclination increased with 2%-points each 5-minutes trial until a [La'] above 4.0 Mmol · l⁻¹ was measured (Figure 4). The athletes described their rate of perceived exertion using Borg RPE 6 – 20 Scale (Borg 1982).

The average VO₂ from the 3rd to the 4th minute was measured during each trial. VO₂ was measured with a sampling time of 30 seconds, using a computerized metabolic system with mixing chamber (Oxygon Pro, Erich Jeger, Hoechberg, Germany). The flow turbine (Triple V, Erich Jeger, Hoechberg, Germany) was calibrated before the first test each day with a 3L, 5530 series, calibration syringe (Hans Rudolph, Kansas City, MO, USA).

We also calculated power output (W) on each trial. To calculate power output on blood lactate profile test and VO₂max test, we used weight (with equipment), speed (m/s), incline (degrees, °) and rolling resistance. This calculation was also done in Excel 2011, in workbook by Thomas Losnegard, NIH (Losnegard, Myklebust, and Hallen 2012).

**Figure 4:** Speed, incline and time schedule for warm up, blood lactate profile test, recovery before VO₂max test and VO₂max test. Specifics for each test are shown.
2.4.2 VO$_{2\text{max}}$ test

After the blood lactate profile test, the athletes were given 15 minutes recovery periods on the same speed and incline as the warm up (Figure 4). This test was also conducted as skating on roller skis, with starting incline (5%) and speed as the first trial on the blood lactate profile test (men: 10.8 km/h, women 9.0 km/h). The incline increased 2%-points every minute up to 15%, and then speed was increased every minute by 0.5 km/h, until exhaustion (Figure 4).

HR was measured continuously; VO$_2$ was registered as mean of every 30 sec, and [La⁻] was taken 1 min after completion of the test, with the same equipment as in the blood lactate profile test. The same skis and poles were used. Borg RPE 6 – 20 Scale was listed (Borg 1982).

We used weight with equipment, speed, incline and rolling resistance to measure maximal power output (W$_{\text{max}}$). W$_{\text{max}}$ is defined as average power output during the last 2 minutes of the VO$_{2\text{max}}$ test. This calculation was also done in Excel 2011, the same way as described in the blood lactate profile test.

VO$_{2\text{max}}$ is calculated as the average of the two highest consecutive measurements. RER above 1.05 and [La⁻] over 8.0 (Mmol · l$^{-1}$) is used as criteria to be sure VO$_{2\text{max}}$ are obtained. Previous research has related the results of tests of maximum aerobic capacity to performance, and it is indicated that RER above 1.05 is necessary to show proper performance and VO$_{2\text{max}}$ (Bellar and Judge 2012). [La⁻] over 8.0 (Mmol · l$^{-1}$) are also known as a good indication that VO$_{2\text{max}}$ is obtained (Aastrand 2003).
2.4.3 20-min all-out trial

On the second test day, the athletes completed a 20 minutes all-out distance test, to determine performance on roller ski treadmill (Figure 5). Participants were informed to do a 15 minutes running warm up, before entering the test laboratory. They also had 15 minutes warm up on roller skis skating on treadmill (with same speed and incline as blood lactate profile test warm up). This is also important to standardize the warm up of the roller ski wheels.

Test started with following speed and incline:
Men: 10.8 km/h – 9%
Women: 9.0 km/h – 9%

We presumed that this speed and incline reflected the average lactate threshold for the athletes, and was a controlled start for the test.

Figure 5: Illustration photo of athlete during 20 min performance test, on roller ski treadmill with roller skis and poles, on Lillehammer University College.
The athletes could after the 1. Minute regulate and determine speed themselves during the remaining 19 minutes of the test. Athletes gave signal “UP” for increase of speed with 0.5 km/h, and signal “DOWN” for reduction of speed with 0.5 km/h. The treadmill measured distance passed, and this determined performance. We also controlled and noted the speed increases and reductions, and distance passed every 2-3 minute.

The participants were unaware of distance and speed on both pre- and post-tests, to eliminate increased performance because of self-perception in progress. We chose this test to give us a picture of how performance will be affected during the training period.

We discussed the possibility of having an outdoor time trial, but because of the coming winter season it would have been impossible to have equal conditions on pre- and post-tests. Post-tests took place in December, and we were unable to conduct an outdoor roller ski time trial at this time of the year (Figure 6). Athletes used the same equipment, such as shoes, roller skis and poles; as on the blood lactate test and VO\textsubscript{2max}.

HR was measured on warm up and continuous during the test, with Polar RS400 (Polar, Kempele, Finland). HR\textsubscript{max}, average HR and HR 1 min after test were noted. After test athletes were asked of level of exhaustion on Borg RPE 6 – 20 Scale. A blood sample was taken 1 min after completed test, and analysed for whole blood [La\textsuperscript{-}] using a blood lactate analyser (Biosen C-line, EKF Diagnostics, Barleben, Germany).
2.4.4 Validity and reliability

The blood lactate profile test and VO2\textsubscript{max} test was conducted by a highly qualified and experienced test manager at Lillehammer University College, so that we could be confident that these tests were conducted in a timely manner with high reliability. It has also been concluded in a study that a continuous horizontal treadmill protocol, like ours, results in reliable measurements of both LT and VO2\textsubscript{max} in male runners (Weltman et al. 1990). We consider the lab and associated equipment to be highly reliable, since all tests had similar environmental conditions; 18 – 21 °C, the roller ski treadmill and same roller skis secured similar speed and inclines. We also consider the measuring instruments to be reliable; the laboratory lactate analyser has an accuracy of CV ≤ 3% at 12 Mmol/L (Biosen 2006), and the way to measure VO2 is reported to be reliable (Dlugosz 2013). Our test manager also calibrated the flow turbine each day to make sure each test day was similar and reliable. We controlled the male and female results separately, to be confident that the male and female measurements gave similar results.

The 20-min all-out trial was conducted in such a way as to create high reliability, since the same procedures were used on all tests, as regards warming up etc. The same treadmill and roller skis assured equal resistance, and the test manager did not inform athletes of expected results during testing so as not to motivate or demotivate the athlete, which could affect performance and result.

We assess the validity of our test battery to be strong. We chose tests that could give us a wide range of results and provide answers to all of our hypotheses in a good fashion. The continuous horizontal treadmill protocol we used in our blood lactate profile test and the VO2\textsubscript{max} test has in a previous study resulted in valid measurement of LT and VO2\textsubscript{max} (Weltman et al. 1990). Two of the most important physiological determinants in endurance sports are VO2\textsubscript{max} and LT (Losnegard, Myklebust, and Hallen 2012; Ingjer 1991; Ingjer 1991; Ainegren et al. 2012; Bassett and Howley 200), and we therefore consider our tests of LT and VO2\textsubscript{max} to be valid.
We added the 20-min all-out trial, since it has not been done in previous similar studies (Ronnestad, Hansen and Ellefsen 2012; Ronnestad et al. 2012), to create higher validity by providing a larger data set that can allow us to discuss the effect of the intervention period further. We chose to conduct all tests in skating to make the tests as valid as possible. It was important for us to eliminate any uncertainty regarding test results, if the tests weren’t conducted in a cross-country skiing technique.

2.5 Statistics
All values are presented in the text, tables and figures as mean ± standard deviation. The individual data points are also presented in figures. For statistic tests between groups we used unpaired Students t-tests, and between each group pre and post we used paired Students t-tests. Students t-tests were done in Excel 2011 (Microsoft Corporation, Redmond, WA, USA). To estimate power output at 4.0 Mmol · l⁻¹ [La⁻], we used [La⁻] and VO₂ on submaximal trials in a third-order polynomial regression. This estimation was also done in Excel 2011, in workbook by Bent Ronnestad, HIL. All statistic analyses resulting in p ≤ 0.05 are considered as statistically significant. All statistic analyses resulting in p ≤ 0.1 are considered to have a tendency to improvement. Mean effect size (ES) was calculated as Cohen’s d to compare the significance of the performance improvements in 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 values above 2.0 is considered to be very large (Hopkins 2000).
2.6 Ethical considerations

The local ethics committee at Lillehammer University College has approved this study, and the Protection Officer and the Norwegian Data Protection Authority has approved the project.

We have used an internationally recognised protocol, and the methods and procedures are designed not to contain risks and complications for the participants. They could at any time withdraw from the project, and they signed a contract, which said that all tests and results are confidential and will be used in this project only. All tests were done on a roller ski treadmill, and the participants were secured by safety belts so as to reduce the possibility for accidents or injury. The test laboratory has specific insurance for the participants. The subjects had to push themselves to exhaustion. We followed the ethical considerations in the Helsinki Declaration.

Participants received 4 free professional tests providing information regarding their physiological abilities and improvements over the training period. Athletes were recruited through cross-country and biathlete trainers and flyers in Lillehammer.

2.7 Plan of research

![Figure 6: Illustration of the plan of research](image-url)
3.0 Results

3.1 Baseline
There were no significant difference between BP and TRAD before the intervention period with respect to previous training, body mass, \( \text{VO}_{2\text{max}} \), \( W_{\text{max}} \), power output at 4.0 \([\text{La}^-]\) (Mmol · l\(^{-1}\)) and performance.

3.2 Blood lactate profile
There was no significant change in \( \text{VO}_2 \) for any of the groups (Table 5). Relative change between groups was small on all 5 min trials (ES: 0.35, 0.38 and 0.41, respectively).

The BP group had significant change in HR on all the three trials, with an average reduction of 4.1 ± 4.5% (p = 0.036), 2.8 ± 3.9% (p = 0.030) and 2.0 ± 2.3% (p = 0.028), respectively (Table 5). The TRAD group had negligible changes in HR on all trials. Relative change between groups was moderate on the first trial (ES: 0.87), small on the second trials (ES: 0.55) and moderate on the third trial (ES: 0.64).

[La\(^-\)] after each trial showed a tendency to change for the BP group on the first and third trial with an average reduction of -14 ± 36% (p = 0.057) and -7 ± 13% (p = 0.083), respectively (Table 5). On the second trial the BP group had a significant reduction of -14 ± 22% (p = 0.048). The TRAD group had a significant reduction of 24 ± 25% (p = 0.022) on the first trial, but no significant changes on the two next trials with an average reduction of -10 ± 18% (p = 0.104) and -4 ± 26% (p = 0.281), respectively (Table 5). Effect size showed that the relative change between groups was small on the first and second trial (ES: 0.32 – 0.20), and trivial on the last trial (ES: 0.15). Changes for men and women were equal, and mean values are presented.
### Table 5: Results from blood lactate profile test before (Pre) and after five weeks of intervention period (Post).

<table>
<thead>
<tr>
<th>10,8/9 km/t – 5%</th>
<th>BP</th>
<th>TRAD</th>
<th>HFKV vs. LFLV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>% Change</td>
</tr>
<tr>
<td>VO₂ (mL · kg⁻¹ · min⁻¹)</td>
<td>39.1 ± 4.3</td>
<td>39.3 ± 3.6</td>
<td>0.3 ± 5.7</td>
</tr>
<tr>
<td>RER</td>
<td>0.90 ± 0.05</td>
<td>0.90 ± 0.05</td>
<td>-0.1 ± 4.5</td>
</tr>
<tr>
<td>HR (beats min⁻¹)</td>
<td>149 ± 14</td>
<td>145 ± 10</td>
<td>-4.1 ± 4.5*</td>
</tr>
<tr>
<td>[La⁻] (Mmol · l⁻¹)</td>
<td>1.8 ± 1.2</td>
<td>1.4 ± 0.6</td>
<td>-13.7 ± 35.6$</td>
</tr>
<tr>
<td>Borg</td>
<td>11.4 ± 2.2</td>
<td>10.8 ± 2.0</td>
<td>-7.1 ± 12.5</td>
</tr>
</tbody>
</table>

| 10,8/9 km/t - 7% |
|------------------|----------------|----------------|----------------|
|                  | Pre | Post | % Change | Pre | Post | % Change | Effect Size |
| VO₂ (mL · kg⁻¹ · min⁻¹) | 47.2 ± 4.4 | 47.7 ± 3.9 | 1.3 ± 2.9 | 49.2 ± 4.2 | 49.3 ± 4.5 | 0.3 ± 2.3 | 0.38 |
| RER              | 0.93 ± 0.05 | 0.92 ± 0.05 | -0.9 ± 2.9 | 0.95 ± 0.04 | 0.95 ± 0.05 | 0.2 ± 2.8 | 0.39 |
| HR (beats min⁻¹) | 165 ± 11 | 160 ± 11 | -2.8 ± 3.9* | 168 ± 10 | 166 ± 5 | -0.7 ± 3.7 | 0.55 |
| [La⁻] (Mmol · l⁻¹) | 2.5 ± 1.6 | 2.1 ± 1.3 | -13.5 ± 21.9* | 3.4 ± 2.2 | 3.1 ± 2.3 | -9.5 ± 18.4 | 0.20 |
| Borg             | 13.5 ± 1.5 | 12.9 ± 1.7 | -4.9 ± 8.2$ | 14.1 ± 1.3 | 13.9 ± 1.7 | -1.8 ± 5.0 | 0.46 |

| 10,8/9 km/t – 9% |
|------------------|----------------|----------------|----------------|
|                  | Pre | Post | % Change | Pre | Post | % Change | Effect Size |
| VO₂ (mL · kg⁻¹ · min⁻¹) | 53.4 ± 5.0 | 54.6 ± 5.1 | 2.4 ± 4.5 | 55.6 ± 4.9 | 55.9 ± 5.6 | 0.5 ± 4.7 | 0.41 |
| RER              | 0.96 ± 0.03 | 0.95 ± 0.03 | -1.0 ± 2.3 | 0.99 ± 0.03 | 0.99 ± 0.02 | 1.3 ± 4.2 | 0.68 |
| HR (beats min⁻¹) | 177 ± 11 | 173 ± 12 | -2.0 ± 2.3* | 178 ± 10 | 178 ± 6 | 0.0 ± 3.8 | 0.64 |
| [La⁻] (Mmol · l⁻¹) | 3.8 ± 1.5 | 3.5 ± 0.2 | -7.3 ± 13.2$ | 5.3 ± 1.8 | 4.8 ± 1.3 | -4.3 ± 25.5 | 0.15 |
| Borg             | 15.2 ± 1.6 | 15.0 ± 1.9 | -1.3 ± 9.6 | 15.6 ± 1.3 | 16.0 ± 1.3 | 2.6 ± 6.6 | 0.47 |

Values are presented as mean ± standard deviation and % change from first test (Pre) to second test (Post).

VO₂max maximal oxygen consumption; RER respiratory exchange ratio; HRmax maximal heart rate; [La⁻] blood lactate concentration; Borg perceived exertion

* Significant change from Pre to Post (p < 0.05)
$ Tendency to change from Pre to Post (p = 0.06 – 0.10)
Power output at 4 Mmol · l⁻¹ [La⁻] showed a tendency to increase for the BP group with an average increase by 5.7 ± 9.7% (p = 0.10), while TRAD did not change (2.3 ± 4.4%, p = 0.20; Figure 7). Effect size of the relative change between groups was small (ES: 0.45).

**Figure 7:** Estimated power output at 4 Mmol · l⁻¹ [La⁻] before (Pre), and after the five week intervention period (Post). For explanation of BP and TRAD, the reader is referred to Figure 6. Mean and individual values are presented as columns and points, respectively.

$ S $ Tendency to change from Pre to Post (p = 0.06 – 0.10)
Estimated % of VO$_{2\text{max}}$ at 4 Mmol · 1$^{-1}$ [La$^-$], showed no significant changes for either BP (2.7 ± 5.2 percent points; p = 0.15) or TRAD (0.9 ± 6.1 percent points; p = 0.73), respectively (Figure 8). Effect size of the relative change between groups was small (ES: 0.32).

Figure 8: Estimated LT shown as % of VO$_{2\text{max}}$ at 4 Mmol · 1$^{-1}$ [La$^-$] before (Pre), and after the five week intervention period (Post). For explanation of BP and TRAD, the reader is referred to Figure 6. Mean and individual values are presented as columns and points, respectively.
3.3 VO\textsubscript{2max}

BP had a significant increase in absolute VO\textsubscript{2max} (mL \cdot min\textsuperscript{-1}), with an average improvement of 2.0 ± 2.5% (p = 0.05; Table 6). There were no significant changes for TRAD (-0.1 ± 3.0%; p = 0.75). Effect size of the relative change between groups was moderate (ES: 0.76).

Table 6: Results from VO\textsubscript{2max} test before (Pre), and after five weeks of intervention period (Post).

<table>
<thead>
<tr>
<th></th>
<th>BP</th>
<th>TRAD</th>
<th>BP vs. TRAD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre (mL \cdot kg\textsuperscript{-1} \cdot min\textsuperscript{-1})</td>
<td>Post (mL \cdot kg\textsuperscript{-1} \cdot min\textsuperscript{-1})</td>
<td>% Change</td>
</tr>
<tr>
<td>VO\textsubscript{2max}</td>
<td>64.9 ± 6.4</td>
<td>66.5 ± 6.5</td>
<td>2.6 ± 3.6*</td>
</tr>
<tr>
<td>VO\textsubscript{2max}</td>
<td>4626 ± 946</td>
<td>4714 ± 966</td>
<td>2.0 ± 2.5*</td>
</tr>
<tr>
<td>RER</td>
<td>1.18 ± 0.06</td>
<td>1.18 ± 0.05</td>
<td>0.9 ± 5.6</td>
</tr>
<tr>
<td>HR\textsubscript{max} (beats min\textsuperscript{-1})</td>
<td>193 ± 9</td>
<td>193 ± 9</td>
<td>0.0 ± 3.0</td>
</tr>
<tr>
<td>[La\textsuperscript{-}] (Mmol \cdot l\textsuperscript{-1})</td>
<td>11.5 ± 2.5</td>
<td>12.1 ± 2.4</td>
<td>4.6 ± 23.9</td>
</tr>
<tr>
<td>Borg</td>
<td>19.0 ± 0.8</td>
<td>19.6 ± 0.7</td>
<td>2.7 ± 3.9</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation and % change from first test (Pre) to second test (Post).

VO\textsubscript{2max} maximal oxygen consumption; RER respiratory exchange ratio; HR\textsubscript{max} maximal heart rate; [La\textsuperscript{-}] blood lactate concentration; Borg perceived exertion

* Significant change from Pre to Post (p ≤ 0.05)
$W_{\text{max}}$ showed that BP had a significant increase of $3.8 \pm 4.3\%$ (p = 0.016; Figure 9). TRAD did not significantly change $W_{\text{max}}$ (-2.5 $\pm$ 6.6\%, p = 0.241; Figure 9). Effect size of the relative change between groups was moderate (ES: 1.11).

*Figure 9: Maximal aerobic power output ($W_{\text{max}}$) before (Pre), and after the five week intervention period (Post). For explanation of BP and TRAD, the reader is referred to Figure 6. Mean and individual values are presented respectively as columns and points.

* - Significant change from Pre to Post (p $\leq$ 0.05)
3.4 20-min all-out trial

There were no significant changes in performance in either BP (1.2 ± 3.9%; p = 0.468) or TRAD (2.9 ± 5.3%; p = 0.138, Figure 10). Effect size of relative change between groups was small (ES: 0.37).

**Figure 10:** 20 minutes performance test before (Pre), and after the five weeks intervention period (Post). For explanation of BP and TRAD, the reader is referred to Figure 6. Mean and individual values are presented as columns and points, respectively.
4.0 Discussion

The most important finding in this study was that block periodization of high intensity endurance training led to significant improvements in \( VO_{2\text{max}} \) and \( W_{\text{max}} \) for the BP group, while this did not happen for the TRAD group. The results from the \( VO_{2\text{max}} \) test showed moderate differences in relative change between groups on both \( VO_{2\text{max}} \) and \( W_{\text{max}} \) (ES=0.76 and 1.11, respectively). In addition, the BP group had significant reduction in HR on the lactate profile test, while the TRAD group did not change. The difference in relative change between groups was moderate on the first and third 5-minute trial (ES=0.87 and 0.64, respectively). As far as we are aware, this is the first study to show a significant change in \( VO_{2\text{max}} \) and \( W_{\text{max}} \), as a result of block periodization of the high intensity endurance training, for cross-country skiers and biathletes.

\( VO_{2\text{max}} \) and \( W_{\text{max}} \)

We expected the biggest changes on the \( VO_{2\text{max}} \) test because of the amount of HIT sessions in the intervention period, and how they were conducted: HIT has a major influence on \( VO_{2\text{max}} \) (Blomquist and Saltin 1983; Astorino et al. 2012), and longer exertion periods are important in endurance sports (Gosselin et al. 2011; Sandbakk et al. 2013). The intensity has to be high, and HR above 88% of \( HR_{\text{max}} \) is positive for endurance athletes (Blomquist and Saltin 1983; Astorino et al. 2012; Gosselin et al. 2011; Storen et al. 2011; Helgerud et al. 2007; Moffat 1977).

The BP group had significant improvement on both \( VO_{2\text{max}} \) and \( W_{\text{max}} \). The TRAD group conducted an equal amount of HIT as BP, and we expected that they also could increase their \( VO_{2\text{max}} \), however this was not the case. After controlling the training diaries we concluded that the training intensity was as high as expected (I4-5: 87 – 97% of \( HR_{\text{max}} \)), with no difference between groups, and wasn’t too low as to not affect \( VO_{2\text{max}} \) (Gosselin et al. 2011; Storen et al. 2011; Daussin et al. 2008; Seiler, Olesen and Hetlelid 2011; Helgerud et al. 2007). This intensity should give a high enough exercise stimulus to increase the cardiac stroke volume (Bassett and Howley 2000; Astorino et al. 2012; Helgerud et al. 2007; Billat et al. 1999; Enoksen, Shalfawi and Tonnessen 2011).
The increase in VO2max for the BP group is therefore probably due to increased cardiac stroke volume. We presume that the relative high-performance level in both groups at pre intervention and the relative short intervention period of 5 weeks was the main reason for no change in VO2max for the TRAD group (BP; 65 ± 6 mL · kg⁻¹ · min⁻¹, TRAD; 64 ± 8 mL · kg⁻¹ · min⁻¹) (Bassett and Howley 2000; Sandbakk et al 2010; Karp 2007; Billat et al. 2001). The endurance training factors have limitations for how much they can influence performance efficacy (Bassett and Howley 2000; Amann 2012), confirming therefore that it is difficult to improve from an existing high level of training. Eventually, VO2max, LT and work economy will stagnate (Sandbakk et al. 2010; Karp 2007; Billat et al. 2001).

The last month before the pre-test both groups conducted approximately 2 HIT sessions per week (Table 2), and the TRAD group did therefore not change as to how the periodization of the HIT sessions was conducted from the pre-intervention to the intervention period. The limitations and drawbacks of TRAD regarding the demands on top-level athletes are important to try to explain the different stimuli on BP versus TRAD (Issurin 2008). Negative interactions between non-compatible workloads that induce conflicting training responses, and insufficient stimuli to help top athletes to progress, could have affected the TRAD groups training outcome (ibid.). However, statistical superior improvements are found when comparing BP with constant repetition programs (Kiely 2012).

We want to emphasize that the TRAD group in this study had a variation in number of HIT sessions each week (i.e. 2-2-3-2-2, Figure 1), and this has not been done in previous studies (García-Pallarés et al. 2010; Breil et al. 2010; Ronnestad, Hansen and Ellefsen 2012; Ronnestad et al. 2012). Previous studies have compared the experimental groups against groups with no variation, and have to some extent only demonstrated the importance of variation as an important aspect of effective training (Kiely 2012). Variation is a necessary component of effective training (ibid.), and we therefore want to point out that the TRAD group had variation during the intervention period by having 3 HIT sessions in the third week. The evidence suggests that variation is a necessary component of effective training, and that monotone training lacking variation leads to overtraining syndrome, poor performance and minor infections (ibid.). This is not the case in our study.
We want to point out that the total number of HIT sessions in the TRAD group also
was for methodological reasons, and we didn’t want other variations in the
methodology to contribute an element of uncertainly. Previous studies have had
differences between groups regarding the amount of HIT and length of intervention
period (García-Pallarés et al. 2010; Breil et al. 2010), and we wanted our groups to
conduct the same amount of HIT within equal time frames.

$W_{\text{max}}$ showed a significant increase for the BP group, while the TRAD group had no
significant changes. The effect size of changes in $W_{\text{max}}$ revealed a moderate effect of
performing BP (ES: 1.11). This shows that BP improves performance on the VO$_{2\text{max}}$
test, and that the athletes improve their maximal aerobic power. This means in theory
that they can work on higher speed and/or inclines at maximal workloads. Previous
studies done on world-class kayakers (García-Pallarés et al. 2010) and alpine skiers
(Breil et al. 2010) support our findings regarding VO$_{2\text{max}}$.

Studies done on both cross-country skiers, cyclists and runners find a strong
correlation between $W_{\text{max}}$ and endurance performance (Anton et al. 2007; Balmer,
Davison and Bird 2000; Bentley et al. 1998; Hawley and Noakes 1992; Ronnestad
and Mujika 2013; Sandbakk, Hegge and Ettema 2013), and a change in $W_{\text{max}}$ is
probably more important for performance than the VO$_{2\text{max}}$ (Anton et al. 2007; Balmer,
Davison and Bird 2000; Bentley et al. 1998). $W_{\text{max}}$ distinguishes well-trained cyclists
from elite cyclists, and is a good predictor of cycling performance (Anton et al. 2007;
Balmer, Davison and Bird 2000; Bentley et al. 1998), while there seems not to be any
major differences between them in terms of VO$_{2\text{max}}$ (Coyle et al. 1991 and Lucia et al.
1998). Even though there is a known relationship between VO$_{2\text{max}}$ and $W_{\text{max}}$, it
appears that $W_{\text{max}}$ is the most important criteria separating well-trained cyclists from
elite cyclists (Lucia et al. 1998). This reinforces the positive results for the BP group,
and indicates increased performance. It was therefore unanticipated that the BP group
would not improve on the 20-min all-out trial (Figure 10).
**Blood lactate profile**

The most important changes in the blood lactate profile test was the improvement in HR and [La\(^{-}\)] for the BP group. The two first trials are under LT and the third trial is approximately at LT. The BP group had a significant decrease in HR during all trials on the blood lactate profile test. The effect size showed a moderate effect of performing BP on the first and third trial (ES: 0.87 and 0.64), and achieved a moderate effect on the second trial (ES: 0.55). However, the reduction in HR for the BP groups cannot be related to improved performance VO\(_2\) in this case, and is probably due to the increased VO\(_{2}\)\(_{\text{max}}\) in Table 6. Since the increase in VO\(_{2}\)\(_{\text{max}}\) is probably due to increased stroke volume, it is natural to assume that HR decreases on submaximal loads, since the increased amount of blood pumped on each stroke reduces the need for frequent strokes (Ingjer 1991; Bassett and Howley 2000; Astorino et al. 2012; Helgerud et al. 2007; Wagner 1991).

BP also had a significant decrease in [La\(^{-}\)] in the second trial, and tendency to decrease on the first (p=0.057) and third trial (p=0.083). The TRAD group only had a significant decrease in [La\(^{-}\)] on the first trial, and no increase in any trials regarding HR. The relative change between groups was minimal (ES: 0.32, 0.20 and 0.15, respectively) in all three trials. The decrease in [La\(^{-}\)] was relatively large for the BP group, with respectively 14 ± 36, 14 ± 22 and 7 ± 13% in the three trials. The BP group also had lower average [La\(^{-}\)] levels than the TRAD group at pre intervention. Since improvement in LT and work economy eventually stagnates when the performance level increases (Sandbakk et al. 2010; Karp 2007; Billat et al. 2001), the improvement for the BP group in [La\(^{-}\)] support a good effect of block periodization. The TRAD group had a significant decrease with 23.5 ± 25.3% on the first trial. This was somewhat unexpected, since a significant decrease on the first trial can indicate an improved LT (Aastrand, Rodahl and Stromme 2003). But this was not the case, since the other results on the blood lactate profile test doesn’t support TRAD as strong as [La\(^{-}\)] in first trial.
The VO$_2$ in the blood lactate profile test didn’t correspond to the decrease in HR and [La$^-$]. There were no significant changes in any of the three trials for both groups (Table 5), and they therefore show no difference in work economy. The VO$_2$ on all submaximal trials did not change, and VO$_2$ should have been reduced from pre to post testing to show improvement in work economy (Svedenhag, Shepard and Aastrand 2002).

Previous studies have shown that both LIT and HIT has positive effect for improvement of LT (Helgerud et al. 2001, 2007), and measurements during the blood lactate profile are partly in agreement with these studies. The decrease in [La$^-$] and HR for the BP group was expected according to precious studies (Shepard 1968; Midgley, McNaughton and Wilkinson 2006). Previous studies show that the BP group improved LT more than the TRAD group (Breil et al. 2006; Ronnestad, Hansen and Ellefsen 2012; Ronnestad et al. 2012). Since the participants are top trained performance athletes no large improvements were expected, since previous studies have shown that the development of LT and work economy eventually will stagnate (Sandbakk et al. 2010; Karp 2007; Billat et al. 2001).

The BP group had a tendency to improved LT, expressed as absolute workload (Figure 7). The lower [La$^-$] on all three trials gives the BP group a slightly higher LT expressed as absolute workload, since the absolute workload on 4 Mmol [La$^-$] probably will be higher when [La$^-$] is lower on workloads under LT. However, the VO$_{2\text{max}}$ here is also important to explain the decrease in [La$^-$]. Higher VO$_{2\text{max}}$ because of increased cardiac stroke volume probably gives better absorption transporting O$_2$ and decreases lack of O$_2$ to energy release processes and possibly prevents lactate accumulation (Bassett and Howley 2000; Gosselin et al. 2011; Daussin et al. 2008). The LT expressed as % of VO$_{2\text{max}}$ showed no improvements.

If anything, the BP group was closer to an increase (2.7 percent points versus 0.9 percent points). A moderate ES could have shown that the athletes in the BP group could use a higher amount of their VO$_2$ capacity. This means that athletes can have higher energy consumption, without the accumulation of [La$^-$] in the muscles (Losnegard, Myklebust, and Hallen 2012; Evertsen, Medbo and Bonen 2001).
It is natural that this leads to increased performance (Losnegard, Myklebust, and Hallen 2012), especially over longer distances, since previous research has shown that improvement in LT is not so critical in competitions with duration fewer than 15 minutes (Stoa et al. 2010; Brandon 1995). But the relative change between the groups was only small, and therefore it is difficult to conclude anything regarding the blood lactate profile test.

20-min all-out trial

In the performance test, none of the groups significantly changed, and the relative change between the groups was small (ES: 0.37). We expected that if the groups increased their VO$_{2\text{max}}$, it would lead to better performance as well, since VO$_{2\text{max}}$ is an important factor for success in endurance sports (Ingjer 1991). It was therefore unexpected that there were no differences in the performance test, especially when the BP group had improvements on both VO$_{2\text{max}}$ and W$_{\text{max}}$, and the TRAD group didn’t have improvement on either VO$_{2\text{max}}$, W$_{\text{max}}$ and the blood lactate profile test.

Previous studies done on world-class kayakers (García-Pallarès et al. 2010) and alpine skiers (Breil et al. 2010) supports our findings regarding VO$_{2\text{max}}$, while our performance test didn’t confirm the same results. This can also be due to limitations in method, which may have influenced results (Ronnestad, Hansen and Ellefsen 2012). Reduced energy consumption at the submaximal loads, and better work economy, could have raised the question of different result increases in a longer test (Losnegard, Myklebust, and Hallen 2012; Billat et al. 1994; Evertsen, Medbo and Bonen 2001), but the blood lactate profile test did not show any differences, especially not for the TRAD group.

The performance test was a new type of test for all of the participants. It is reasonable to think that it would be better with a test outside where they increased and lowered their speed naturally, and didn’t have to request higher or lower speed. But due to the conditions outside, it was impossible to get a satisfactory test at the time.
The course profile was also different from normal competition profiles, and since the participants not only trained uphill, it is based on previous results on cross-country skiers and runners therefore it is reasonable to think that they would have a larger improvement if they practiced even more specific HIT sessions (Ainegren et al. 2012; Hayes, French and Thomas 2011).

It is important to specify that the project was conducted early during the competitive season, and that the group competitors probably had already attained a high level before the project began, since important competitions were coming up during the first weeks after the intervention. The high preparation level of the athletes, relative to performance in their sport and to the fact that it was early in the competition season, were important to get useful insight on how periodization of shorter training periods affect the training outcome. The recent attention on short intervals with focus on improving a few selected abilities (Issurin 2010; Storen et al. 2011) seems to have an effect on some performance determinants in cross-country skiers and biathletes.

A review supports the increase in VO\textsubscript{2\text{max}} observed in the BP group: The athletes in the BP group probably got maximum training effect, while giving priority to few skills each week, instead of giving attention to several abilities at once (Issurin 2010). The high amount of HIT sessions should increase VO\textsubscript{2\text{max}} for both groups (Olympiatoppen 2012; Blomqvist and Saltin 1983; Astorino 2012; Gosselin et al. 2011; Storen et al. 2011), but only the BP group improved. This means that top trained athletes maximize the total training effect, when fitness adaptions are developed in a sequential hierarchy with carefully selected fitness components, at least for a short period.

The athletes in the project have trained systematically for several years, and it seems that the change in the periodization of the training for the BP group gave certain results, at least for selected fitness components, like VO\textsubscript{2\text{max}}. The TRAD group did not improve, but the training they have conducted has led to superior adaptions in VO\textsubscript{2\text{max}} in other studies on endurance performance (Olympiatoppen 2012; Blomqvist and Saltin 1983; Astorino 2012). The training organization of the TRAD group didn’t affect the selected fitness components, because of training history, high level pre intervention and relatively short intervention period.
The TRAD group conducted a mixed training program, with focus on HIT and LIT every week, and the results can be explained by the drawbacks of mixed training programs for top trained athletes (32, 33).

Negative interactions between non-compatible workloads can provoke conflict in training responses, and the insufficient training stimuli are descriptive for the limitations of TRAD to help top trained athletes to progress (Kiely 2012, Issurin 2008). It seems that our attempt to overcome these limitations with our BP concept of HIT sessions, have led to superior adaptations, especially for VO$_{2\text{max}}$ and W$_{\text{max}}$, as suggested in previous studies (Issurin 2010).

It is important to notice that our intervention period lasted for only 5 weeks, and it still needs to be investigated further how BP influences training effect for top trained athletes over months and years. The previous study with a 12-week long intervention period with similar study design also showed improvement in VO$_{2\text{max}}$, and a tendency to improvement in LT in elite cyclists (Ronnestad et al. 2012). They also discovered improvement in performance, and this can indicate that BP can give superior differences also on longer time periods than 5 weeks. The increased performance in the 12-week study can also indicate that if our intervention period was over a longer time period our performance test could achieve a different result.
Block periodization of the high intensity training led to significant higher VO$_{2\text{max}}$ and $W_{\text{max}}$, which was not the case with traditional organization of the high intensity training. A moderate ES on both VO$_{2\text{max}}$ (ES: 0.76) and $W_{\text{max}}$ (ES: 1.11) support therefore that block periodization leads to improved performance in these measurements. The blood lactate profile test did not support block periodization as strong as the VO$_{2\text{max}}$ test, but the results can support the improvement for the BP group partly. The performance test however, didn’t show any significant differences. We therefore confirm hypothesis I, that 5 weeks of block periodization improved VO$_{2\text{max}}$ and $W_{\text{max}}$, while no changes occurred in TRAD, when total duration of HIT and LIT is equal. We partly confirm hypothesis II, that 5 weeks of block periodization leads to improved LT, compared to traditional periodization, when total duration of HIT and LIT is equal. We reject hypothesis III, that 5 weeks of block periodization doesn’t lead to improved performance, compared to traditional periodization, when total duration of HIT and LIT is equal. In conclusion these findings are important, and is useful for producing optimal conditions of endurance training for cross-country skiers and biathletes.
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Appendix 1

Literature search

The aim of this study was to give top athletes applicable knowledge of how to best perform periodization of training to improve performance.

Research question:
Does two-block periodization of high intensity endurance interval training, improve VO$_{2\text{max}}$, LT, work economy and performance more than a traditional periodization model with a total equal volume of high intensity endurance training over a 5-week intervention period?

Hypotheses:
I: 5 weeks of block periodization leads to improved VO$_{2\text{max}}$ and maximal power output, compared to traditional periodization, when total duration of HIT and LIT is equal.
II: 5 weeks of block periodization leads to improved LT, compared to traditional periodization, when total duration of HIT and LIT is equal.
III: 5 weeks of block periodization leads to improved performance, compared to traditional periodization, when total duration of HIT and LIT is equal.

What keywords did you use?
Training organization, Block periodization, Traditional periodization, Endurance performance, Lactate threshold, Maximal oxygen consumption, Maximal power output, Performance VO$_2$, Work economy, periodization paradigms, ronnestad, wagner, hallen, sports medicine

Where have you searched?
PubMed, Google Scholar
Searches that returned relevant results

PubMed: Training organization, Block periodization, Endurance performance,
Lactate threshold, Maximal oxygen consumption, Maximal power output,
Performance VO2, Work economy, periodization paradigms, ronnestad

Google Scholar: “Lactate Threshold 8.0 Mmol” “Wagner” “Hallen”

Comments

There is little literature on block periodization on endurance sports, and it was
difficult finding something relevant. A lot of the research on periodization is studies
done on strength etc. PubMed was by far the database with most reliable and useful
literature. I used several keywords that my supervisor showed me, and the “related
articles” section was very useful. Google Scholar was used late in the process to find
relevant literature regarding the reliability and validation of test and test procedures.