Effects of block periodization training versus traditional periodization training in trained cross country skiers

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THE SWEDISH SCHOOL OF SPORT
AND HEALTH SCIENCES
Graduate essay 62: 2013
Master program in sport science: 2012-2013
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Abstract

Aim
The overall aim of this study was to develop a broader understanding on how to optimize the organization of aerobic endurance training programs, and especially how to better organize high-intensity training (HIT) and low intensity training (LIT) to give an optimum endurance performance progress.

Method
This study compared the effects of two different training organization methods in trained cross-country (XC) skiers and biathletes. During a 5 week intervention period, one group of athletes (n = 10, 7 men and 3 women, age 23 ± 9 years) performed block periodization (BP) training with 5-1-3-1-1 HIT sessions in the respective weeks. The other group of athletes (n = 9, 7 men and 2 women, age 22 ± 5) followed a more traditional periodization (TRAD) method performing 2-2-3-2-2 HIT sessions. LIT was interspersed between the HIT sessions so that both groups performed similar total volumes of HIT and LIT during the intervention period.

Results
The BP group increased relative and absolute VO$_{2\text{max}}$ (2.6 ± 3.6% and 2.0 ± 2.5%, P < 0.05) and time to exhaustion (6.1 ± 6.4%, P < 0.01). No changes were seen in the TRAD group on relative or absolute VO$_{2\text{max}}$ (0.8 ± 3.5% and -0.1 ± 3.0%) or time to exhaustion (-2.0 ± 7.7%). Mean effects size (ES) of the relative and absolute improvement in VO$_{2\text{max}}$ and time to exhaustion revealed small to moderate effects of performing BP training vs. TRAD training (ES range from 0.51 to 1.14).

Conclusions
This study indicates that organizing endurance training in XC skiers with block periodization training give better adaptations compared to performing traditional periodization training during a 5 week training period when performing similar volumes of high-intensity and low intensity training.

Keywords: Training organization, block periodization, high-intensity training, endurance performance, maximal oxygen consumption, cross-country skiers.
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1.0 Introduction

Training periodization is a practical branch of training theory. It was established during the 1960s by Soviet scientists for high performance athletes in the former USSR. Later, it took on the status of a monopolistic background for training planning also in the western world (Issurin 2010). In the last 50 years, sport science have accumulated in new knowledge about training, and international sport have change dramatically, however the traditional model of periodization has not changed a lot since the first publications.

Today, athletes compete a lot more compared to two-three decades ago, and there are other demands on the top level athletes. For further performance progress, coaches and athletes have found limitations and drawbacks using traditional periodization (TRAD), including an inability to get multi peak performances during the competition season, drawbacks using long mixed training programs, inducing conflicting training responses and insufficient training stimuli (Issurin 2008; 2010). In response to these limitations, some experiments made by coaches and researchers have led to alternative training programs, and ultimately to block periodization (BP) training.

BP uses specialized mesocycle blocks, which focus on developing a few selected abilities over a short timeframe. In contrast, TRAD focuses on the development of many abilities simultaneously. Using BP enables a larger training stimulus than TRAD, which might lead to better adaptations (Issurin 2008).

There are some recent studies using BP for endurance training on runners, alpine skiers and cyclists (Breil et al. 2010; Garcia-Pallares et al. 2010; Støren et al. 2011; Rønnestad et al. 2012a; Rønnestad et al. 2012b), but there are none using cross-country (XC) skiers or biathletes. Since these sports are very popular in Norway, and especially in the Olympic town of Lillehammer, the present study wants to find out whether BP training also has an effect when skiing.
2.0 Background

For many elite endurance athletes, the base of training periodization is formed by a hierarchical system of training units that are repeated periodically. The upper level of the hierarchical system is the Olympic cycle which lasts four years. The next level is the macrocycles; this cycle lasts one year (or half a year). The macrocycles are then divided into training periods. The training periods are the key functions in the traditional periodization training, because they split the macrocycles into different parts:

- Preparation period (“base training”)
- Competition period (event specific training and the competition season)
- Recovery period (for recovery)

The last levels of the hierarchical system are mesocycles; which are medium-sized training cycles lasting several weeks, and microcycles; which are small-sized training cycles lasting several days up to one week. The last two units are the building blocks of an elite endurance athlete’s training system (Issurin 2010).

The wave-shape training design was postulated in the 1950s for weekly and monthly programme. It was found that alternating days of high workloads and lower workloads gave greater performance improvements. The same was found when alternating small-, medium-, and high workloads between weeks, and this periodization of the training is still being seen. Today, periodization of the training by athletes is often achieved with alternating the total training workload (volume, frequency and intensity) during e.g. a week (Issurin 2008; 2010).

3.0 Literature

3.1 Training periodization

There are a lot of different ways to organize training intensity zones, the zones are often defined by heart rate (HR) ranges and/or blood lactate concentration ranges. More recent research has found an accepted and well used polarized model which top endurance athletes use worldwide, and in several different sports. Seiler & Kjerland (2006) use three different HR zones; Zone 1: low intensity training (LIT; 60-82% of HR\textsubscript{max}), Zone 2: moderate intensity training (MIT; 83-87% of HR\textsubscript{max}) and Zone 3: high-intensity training (HIT; 88-100% of HR\textsubscript{max}). Traditionally, elite endurance athletes have performed around 75% of their endurance training using LIT (Zone 1), 5% using MIT (Zone 2) and 20% using HIT (Zone 3). This is
called the “polarized endurance training model”. The “75-5-20” distribution is concluded by Seiler & Kjerland (2006) to be near an optimal distribution for training of high performance endurance athletes. This model has been used by Olympic winning Norwegian rowers (Seiler & Kjerland 2006; Laursen 2010), other elite rowers (Steinacker 1993; Steinacker et al. 1998), gold winning track cyclists (Schumacher & Mueller 2002), and elite marathoners (Billat et al. 2001a).

XC skiers have also reported use of the polarized endurance training model with high volumes of LIT and less volumes of MIT and HIT (Gaskill et al. 1999; Vergès et al. 2006; Seiler & Kjerland 2006; Sandbakk et al. 2011). However, Sandbakk et al. (2010) found a periodization of training in elite sprint XC skiers, where they did not use the polarized model during the six months preparation period leading up to the competitive season. The sprint skiers performed more LIT and MIT training than “recommended”, suggesting that LIT and MIT are important factors in “base training” in that time of the year. However, an increasingly polarized training pattern was performed leading up to and in the competition season, with less LIT and MIT, and more HIT performed. The more intensified training (more HIT) leading up to the season seems to be important in optimizing performance before and in the competition season. The study suggested that the higher volumes of LIT and MIT gave the sprint skiers a great training base, so that they could withstand more HIT before and in the competition season.

However, the guidelines of the traditional periodization training model are based on the simultaneous development of many physiological components or target abilities. In the preparation period, high-performance athletes have a mixed training program for simultaneously developing general aerobic- and anaerobic ability, muscle strength, endurance strength, basic technique- and muscle coordination etc. Many of these abilities require specific physiological and psychological adaptations, and some of these adaptations are not compatible, causing conflicting training responses (Issurin, 2008; Mero et al. 1993; Soungatoulin 2003; Steinacker et al. 1998). For the high-performance athletes, these limitations in the traditional periodization are obstacles for further performance progression (Issurin 2010). The traditional periodization training is also characterized by using relative long periods of time for the development of training goals (Garcia-Pallares et al. 2010). Other drawback that has been found with the traditional periodization training are excessive fatigue and the increased risk of overtraining coming from prolonged periods of mixed training.
(Lehman et al. 1997), insufficient training stimulation by mixed training and an inability to provide several peak performances during a season. All of this leads to sub-optimal performance (Issurin 2008; 2010).

### 3.2 Block periodization

When coaches and athletes were trying to overcome these limitations in the training programme, alternative periodization concepts were developed. The recent block periodization model offers an alternative approach for planning the high-performance athlete’s training. The general idea is implementing specialized training blocks (mesocycle-blocks). These blocks contain highly concentrated training workloads directed to a small number of targeted abilities, enabling a larger training stimulus (Issurin, 2008). Issurin (2010) says that block periodization is the use of specialized mesocycle-blocks, where the focus is on concentrated workloads on a few selected abilities at any one time, while maintaining other abilities.

An example of a training block might be a training week with 4-5 HIT sessions, which is called a shock microcycle, and is followed by a week with mostly LIT and active recovery training. Elite athletes training with a traditional training method may not get sufficient workload stimulus to improve performance while trying to develop many physiological abilities simultaneously (Issurin 2008; 2010). However, with these shock microcycles the elite athletes get a sufficient workload stimulus for improving performance.

There have been several recent block periodization training interventions: Garcia-Pallares et al. (2010) found that block periodization training is more effective for improving the performance of top level kayakers than traditional periodization training. Ten world class kayakers were assessed during a training cycle over two consecutive seasons. The traditional training cycle lasted 22 weeks the first season, and a block periodization cycle lasted 12 weeks the second season. Both protocols showed improvements in physiological performance variables, but the block periodization program achieved the same results using half the endurance training volume as the traditional model. They concluded that using block periodization, resulted in a more effective training stimulus for the improvement of performance when comparing with a traditional model, and that using block periodization are a more useful strategy to maintain and improve training effects (Garcia-Pallares et al. 2010).
Another study in elite junior alpine skiers found that block periodization of HIT sessions is an efficient way to improve VO$_{2\text{max}}$ and other performance variables in alpine skiers. The block periodization group performed 15 HIT sessions in 11 days. The control group went on with their conventional mixed training. The block periodization group completed a higher amount of HIT than the control group. The block periodization group improved VO$_{2\text{max}}$ and peak power output. No changes occurred in the control group (Breil et al. 2010). Generally, alpine skiers aim to have as much on-snow training as possible, which reduces the time remaining for endurance training. Endurance training and strength training are often done in parallel with each other. This mixed training can result in less (at least compromised) improvements in both endurance and strength training, and a higher risk of overtraining (Breil et al. 2010).

After Garcia-Pallares et al. (2010) and Breil et al. (2010) it was difficult to determine whether the increase in VO$_{2\text{max}}$ and other performance indicators came from the higher number of HIT sessions in the block periodization group compared to the traditional periodization group, or if it was the nature of the organization of the block periodization.

Rønnestad et al. (2012$^a$) wanted to find out whether the observed differences in physiological performance variables (VO$_{2\text{max}}$ and peak power output) between block periodization training and traditional periodization training were due to the block periodization per se, or if they were due to the increased volume of HIT sessions in the block group. This was the first study where similar volumes of HIT and LIT were done in both the BP training group and the TRAD training group. Trained cyclists were divided into the two groups. The BP group had one week of five HIT sessions, followed by three weeks of one HIT session per week (5-1-1-1), and having a naturally high volume of LIT. The TRAD group had two HIT sessions per week for four weeks (2-2-2-2) and a naturally high volume of LIT. Although similar volumes of HIT and LIT were performed, the BP group increased VO$_{2\text{max}}$ and peak power output, but no changes occurred in the TRAD group. The study found that block periodization provides superior training effects in trained cyclists compared to traditional periodization (Rønnestad et al. 2012$^a$).

When block periodization training provided superior adaptations during a 4 week training intervention, Rønnestad et al. (2012$^b$) repeated the study mentioned but increased the training intervention to 12 weeks (BP group 5-1-1-1 x 3; TRAD group 2-2-2-2 x 3). In this study, the same results were seen; the BP group achieved a larger relative improvement in VO$_{2\text{max}}$ and
other endurance and performance indices compared to the TRAD group. All this were done when similar total volumes of HIT and LIT were performed, suggesting that block periodization training may be a good alternative for endurance athletes.

As seen, there are studies using BP on runners, alpine skiers and cyclists, but as mentioned before, there are none using cross country (XC) skiers or biathletes. XC skiing is performed in varied terrain, while using classic or skating style, both with several different sub-techniques, which have different demands on different muscles all over the body. All the different styles and techniques must be included in training, however studies on XC skiers have shown that only a relatively moderate amount of sport specific training (e.g. skiing on snow and roller skiing; ~ 60%) are performed in the preparation period when compared to running and cycling (Lucia et al. 2000; Esteve-Lanao et al. 2007; Losnegard et al. 2013).

3.3 HIT or LIT to improve performance

There are many different factors in determining success in an aerobic endurance sport; a model describes three factors that are important for aerobic endurance performance; maximal oxygen uptake ($VO_{2\text{max}}$), lactate threshold and work economy (Pate & Kriska 1984). More recent studies support this model (Bunc & Heller 1989; di Prampero et al. 1986; Helgerud 1994; Hoff et al. 2002). The single most important factor is probably $VO_{2\text{max}}$, since $VO_{2\text{max}}$ is regarded as the best single indicator of an individual’s cardiorespiratory capacity (Åstrand et al. 1964; Saltin & Åstrand 1967; di Prampero 2003), and XC skiers have been reported in the literature to have some of the highest $VO_{2\text{max}}$ values ever seen (Ingjer 1991). For performance in modern XC skiing, the importance of $VO_{2\text{max}}$ is unquestionable, top level athletes needs a very high $VO_{2\text{max}}$ (Saltin & Åstrand 1967; Losnegard 2012) and top level skiers have higher $VO_{2\text{max}}$ than lower level skiers (Ingjer 1991; Sandbakk et al. 2011).

Improvements in $VO_{2\text{max}}$ may be done with both LIT and HIT (Helgerud et al. 2001; 2007, Stephen et al. 2007, Laursen, 2010). HIT is repeated short to long bouts of high-intensity exercise with recovery periods between each bout (Buchheit & Laursen 2013) and HIT gives fluctuations in the O2 uptake, and gives repeated disturbances of cellular homeostasis (Daussin et al. 2008). There are several studies indicating that HIT is more effective than LIT in improving $VO_{2\text{max}}$ and generally the physiological endurance performance in sedentary, recreational, active and elite individuals (Laursen & Jenkins 2002; Helgerud et al, 2007; Daussin et al., 2007; Daussin et al., 2008). How much improvement in $VO_{2\text{max}}$ training gives,
depends on training status, training intensity, duration and frequency of training sessions (Shepard 1968, Seiler & Kjerland 2006, Helgerud et al. 2007). When the performance level of the athletes improve, it might seem important to have an even higher intensity of the aerobic endurance training to still get further improvements (Shepard 1968).

There have been various HIT protocols that have successfully improved physiological endurance performance. The magnitude of training adaptations depends on the duration, intensity and frequency of the HIT bouts. Supramaximal sprint intervals (15—45 sec) at 175% of peak power output (PPO), maximal speed intervals and longer intervals (4-6 min) at ± 80% PPO or 90-95% of HR_{max} all improve aerobic (and anaerobic) performance (Billat 2001b; Laursen et al. 2002; Helgerud et al. 2007; Macpherson et al. 2011).

Some studies using sessions of 4 x 4 min at 90-95% of HR_{max} with 3 minutes of active recovery in their HIT protocols have shown improved VO_{2max} in trained soccer players (Helgerud et al. 2001; 2007; Hoff et al. 2002b). Helgerud et al. (2007) argued that training at an intensity of 90 - 95% of HRmax will improve VO_{2max} by increasing SV and Q_{max} (central adaptations).

There are debates on what kind of interval duration is the most effective way in improving VO_{2max}. Helgerud et al. (2007) said that “up to an intensity approximating VO_{2max}, intensity determines the training response, not the duration”. Training at 90-95% of HR_{max}, gave better improvements in VO_{2max} than threshold training at 85% and continuous training at 70 % HR_{max}. The study found greater cardiovascular effects at a higher intensity. However, Seiler et al. (2011) found that 4 x 8 minutes intervals (at 90% of HF_{max}) gave greater overall gains in VO_{2peak} and power at VO_{2peak} compared to 4 x 4 minutes and 4 x 16 minutes intervals (at 95% and 88% of HF_{max} respectively) over a 7 week interval training period on recreationally trained participants. Comparing the 4 x 16 min and 4 x 8 min intervals, the data is consistent with Helgerud et al. (2007). But, by reducing the work intensity slightly, and prolonging the interval duration, the 4 x 8 achieved better adaptive effects than the 4 x 4 group. It was then suggested that “work duration and intensity are integrated and not independent of each other as signaling components of the adaptive response to training” (Seiler et al. 2013).

Even though HIT sessions is an effective way to increase several endurance parameters, elite athletes do not use HIT more than on average a couple of times per week (Seiler & Tønnessen
Firstly it seems that a combination of LIT and HIT gives the best chance of improving VO_{2max} and other physiological determinants in trained and elite athletes (Seiler & Kjerland 2006; Laursen 2010; Seiler 2010). LIT is effective in improving physiological adaptations (e.g. capillary density) and is not just a “waste of time”. And two HIT sessions per week combined with volumes of LIT seem to be well tolerated by endurance athletes, and it seems two HIT sessions per week is often sufficient in increasing performance without inducing excessive stress (Seiler & Tønnessen 2009), but three or more HIT sessions per week over longer periods have been suggested to induce overtraining symptoms (Billat et al. 1999).

### 3.4 General physiological adaptations

The purpose of exercise training is to change physiological systems in a way where physical capacity is enhanced through an improved capacity. In response to exercise endurance training, and depending on the training status and performance level of the athlete, and the volume, intensity and frequency of the training, changes do occur in central and peripheral systems (e.g. higher stroke volume, higher plasma volume, more oxidative and glycolytic enzyme activity in the muscles, and a higher capillary density). Improved muscle buffering system and fibre type characteristics are also among the positive effects. Some of the adaptations might lead to a higher VO_{2max} and to a generally better physiological capacity (di Prampero 2003; Daussin et al. 2008; Laursen 2010). For example, an improvement in VO_{2max} using HIT may result from both peripheral adaptations (a larger a-v O_2 difference, better mitochondrial function and higher capillary density) and central adaptations (higher SV and Q) (Daussin et al. 2008).

In short, the VO_{2max} is most limited by oxygen supply, and the oxygen delivery to the muscle is determined by the cardiac output (Q), which in turn is determined by stroke volume^{1} (SV) x heart rate (Åstrand et al. 1964; di Prampero, 2003; Hallen 2004).

A large ventricle mass, seen from the Fick principle^{2}, will be an advantage in endurance sports. The ability to pump more blood around the body, gives the working muscles more O_2.

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^{1} SV is the amount of blood pumped out by the left ventricle with each systolic heartbeat. SV, together with HR, determines how much blood the heart can eject per minute (Q). The Q represents the O_2 delivery to for example the working muscles (Åstrand et al. 1964; Hallen 2004).

^{2} The Fick principle states that VO_{2max} is limited by the maximum cardiac output (Q) and the extraction of O_2 by the working muscles.
rich blood and in turn better conditions for the working muscles. Endurance athletes have greater left ventricle mass than non-endurance trained people (Scharag et al. 2002). This indicates that endurance training gives an adaptation of the left ventricle (Naylor et al. 2008). A study found that when the cardiovascular system was pushed to its maximum during HIT, the SV increased likely due to adaptation of the left ventricle and an increase in blood volume, and concluded this was the reason for the improved VO$_{2max}$ (Helgerud et al. 2007).

The classic SV theory states that the SV increases linearly during graded exercise up to 40 % of VO$_{2max}$. After this point the SV plateaus in untrained subjects (Åstrand et al. 1964). However studies have shown that elite endurance athletes increase the SV during graded exercise all the way up to VO$_{2max}$ with no plateau. This has been found in both highly trained cyclists and elite runners (Gledhill et al. 1994; Zhou et al. 2001).

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2 According to the Fick principle, VO$_2$ = cardiac output x (a-v O$_2$ difference). The cardiac output is among the central adaptations, while the a-v O$_2$ difference is among the peripheral adaptations. (The a-v O$_2$ difference is the difference between the amount of O$_2$ in the arterial blood, and the amount of O2 in venous blood. This reflects the amount of O$_2$ from the blood the muscles actually used).
4.0 Aim, objectives and hypotheses

The overall aim is to develop a broader understanding on how to optimize the organization of aerobic training programs, and more directly; how to better organize HIT and LIT to give an optimum endurance performance progress in cross country skiers and biathletes.

The present study measures what happens to VO\(_{2}\max\) and cardiac output adaptations in two different training groups. A time to exhaustion test will compare performance development. One group will do traditional training and the other block periodization training.

1. Will the use of block periodization training give a better improvement in VO\(_{2}\max\) adaptation than traditional periodization training?
   Hypothesis: Both groups will increase VO\(_{2}\max\), but the block periodization training group will increase VO\(_{2}\max\) significantly more than the traditional periodization training group.

2. Will the time to exhaustion increase during the training intervention period?
   Hypothesis: Both groups will increase time to exhaustion, but the block periodization training group will increase time to exhaustion significantly more than the traditional periodization training group.

3. Will the SV and Q values change during the training intervention period?
   Hypothesis: SV and Q will increase in the block periodization group, and no changes will occur in the traditional periodization training group. SV will plateau at the same level for both groups before and after the training intervention period.
5.0 Methods

5.1 Subjects

Nineteen trained males and females volunteered for the project. They were matched and divided into a block periodization group (BP) (n=10) and a traditional periodization group (TRAD) (n=9). Subject characteristics can be seen in Table 1. The subjects were active skiers or biathletes, except for two older male army athletes, who were well training recreational skiers, and were divided in separate groups. The BP group had three females, and the TRAD group had two females. All the participants were over 18 years old. To participate in the project there were a VO$_{2\text{max}}$ limit of $>55$ ml/kg/min and $>50$ ml/kg/min for men and women respectively. The subjects were selected from the training environment in Lillehammer, e.g. from local ski clubs, local biathlon clubs and local cross country and biathlon teams.

Table 1. Subjects’ characteristics. BMI = body mass index. Values are mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>Age (year)</th>
<th>Body mass (kg)</th>
<th>Body height (cm)</th>
<th>BMI</th>
<th>VO$_{2\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP group (n=10)</td>
<td>23 ± 9</td>
<td>71 ± 15</td>
<td>179 ± 16</td>
<td>22 ± 6</td>
<td>64.9 ± 6.4</td>
</tr>
<tr>
<td>TRAD group (n=9)</td>
<td>22 ± 5</td>
<td>74 ± 6</td>
<td>182 ± 9</td>
<td>22 ± 1</td>
<td>63.7 ± 7.9</td>
</tr>
</tbody>
</table>

Top results for each subject from the 2012-2013 competition season were collected, both groups had subjects with podium results from Norwegian Cup and higher, and the mean performance level in both groups were equal. For the senior XC skiers there were some who had taken part in one or more World Cup races (national quota), one had participated in the U23-World Championships, there were several victories and/or podium results in Scandinavian Cup and Norwegian Cup races, and there were a couple of top 10 results in the Norwegian Championship. For the junior XC skiers there was one podium result in the Norwegian Cup combined, and there were several top 10 results from the Norwegian Championships, Norwegian Cup races and qualifying races for the Junior World Championship. One was on the reserve list to participate in the Junior World Championship. For the senior biathlon skiers, one had a podium result in the Norwegian Cup, and there were several top 10 and top 30 results from the same cup.
5.2 Ethical considerations

None of the methods used in the present study are invasive, nothing were taken out from the body expect blood samples from the fingertips. The researcher doing the blood collection had great experience. The blood was collected in a small cup for further analysis. The biological material and the blood collecting tools were thrown in suitable collecting bins, made for dangerous biological materials after usage.

All the tests are standardized; they have been used internationally thousands of times, and have been used hundreds of times in the same lab as the present study used. The researchers have themselves completed the tests several times, and they have been monitoring the tests several times. When going at high speeds on a treadmill with roller skis and poles, there is a risk of falling. When there were subjects that were unsecure or the researchers think there was a higher risk of falling, the subjects used harness tools at the blood lactate profile test. All subjects used harness tools at the VO$_{2\text{max}}$ test. The VO$_{2\text{max}}$ test is quite hard to conduct, but the subjects (athletes) are used to doing them.

All the participants got written information about the project, and told they could leave the project at any time without any consequences. All participants were over the age of 18, so they did not need written consent from other people (e.g. parents).

Normally, a blood lactate profile test and a VO$_{2\text{max}}$ test are quite expensive. In this research, the participants got two blood lactate profile tests and two VO$_{2\text{max}}$ tests for free. That might have been a motivation for participants to enter and being part of the research. The participants did not get any money, nor will they have to pay anything to take part in the research.

The researchers knew most of the participants. The cross country- and biathlon environment is not so big in Lillehammer, everybody knows almost everybody. But that did not affect the research in any way, the participants did their test on machines, and the machines were giving the researchers the results. The results were anonymous, all the participants had their own participants’ number, and the key (participants’ name vs. number) were kept at a different place than the data were stored. Data were stored at a computer with password protection, and backup will also be password protected.
Lillehammer University College has an own insurance for participants attending the research, if anything would have happen to them, they would have been covered by an insurance.

The research was given ethical approval from the local ethical committee at Lillehammer University College. The research followed the ethical standards established by the Helsinki Declaration of 1975 (World Medical Association Inc., 2009). All participants signed an informed consent form before taking part of the study.

5.3 Experimental design

Physical tests (pre- and posttests) were performed before and after a training intervention period. The training intervention lasted 5 weeks and the HIT sessions were organized differently according to two different training models. The BP group had five HIT sessions the first week, then one, then three, then one and one (5-1-3-1-1). The TRAD group performed a more traditionally organized interval training program. This group had two weekly HIT sessions except the third week, when they performed three HIT sessions (2-2-3-2-2). This group basically continued their normal daily training. See an overview in Table 2. The total volume of HIT and HIT were similar in the two groups during the five week-intervention period. The study was conducted during the first phase of the participants’ competition period.

Table 2. Overview of the 5 week training intervention period. It shows the number of HIT sessions per week for block periodization group (BR) and traditional periodization group (TRAD).

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP group HIT</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TRAD group HIT</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Total self reported training hours the last year and the last month before the start of the research were collected; the BP group had performed 589 ± 166 h and 58 ± 7 h, respectively, while the TRAD group had performed 578 ± 90 h and 65 ± 14 h, respectively. Both groups reported having 1-3 HIT sessions per week the last month leading up to the intervention. Both groups had been using a polarized training model.
5.4 Training

The subjects organized the HIT sessions during the week like it suited themselves, but were told to have one day of LIT between each HIT session, except the BP groups’ first week. The endurance training was divided into three HR zones: Zone 1) low intensity training (LIT; 60-82% of HR_{max}), Zone 2) moderate intensity training (MIT; 83-87% of HR_{max}) and Zone 3) high intensity training (HIT; 88-100% of HR_{max}). HR_{max} were determined on the VO_{2max}-test. **Figure 1** presents the relative distribution of the endurance training in the different HR zones during the five week intervention period for both groups. **Table 3** presents the mean weekly training volume during the five week intervention period for both groups. **Table 4** presents the mean total training volume for each week and total training volume combined during the training intervention period for both groups.

![Figure 1](image.png)

**Figure 1.** The figure shows the relative distribution of training volume in the different HR zones during the five week intervention period in BP group and TRAD group.
Table 3. Mean training hours total per week for BP group and TRAD group during the five week intervention period. The training is divided into three heart rate zones of maximal heart rate (% of HFmax): Zone 1: 60-82 %, Zone 2: 83-87 %, Zone 3: 88-100 %. Other can be strength training, speed training etc. Values are presented in mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>BP group</th>
<th>TRAD group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>9.8 ± 1.9</td>
<td>10.6 ± 1.6</td>
</tr>
<tr>
<td>Zone 2</td>
<td>0.1 ± 0.2</td>
<td>0.2 ± 0.2</td>
</tr>
<tr>
<td>Zone 3</td>
<td>1.2 ± 0.2</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>Other</td>
<td>1.5 ± 0.4</td>
<td>0.9 ± 0.6</td>
</tr>
<tr>
<td>Total</td>
<td>12.6 ± 1.8</td>
<td>12.7 ± 2.0</td>
</tr>
</tbody>
</table>

The HIT sessions were conducted as 5 x 6 or 6 x 5 minute interval, in Zone 3, with HR around 90-95 % of HRmax. Active recovery periods were 2 minutes between each bout. The BP group performed 107 ± 16% and the TRAD group performed 95 ± 11% of the total pre-assumed minutes of HIT during the intervention period. Of the total HIT minutes during the intervention period, the BP group performed 72 ± 18% and the TRAD group performed 69 ± 19% using skating technique. The type of skating techniques used during HIT sessions and testing were V1 (V2 is the Swedish name, “paddling”, “gear one”) and V2 (V3 is the Swedish name, “dobbeldans”, “doubledance”) on roller skis or skiing on snow. The rest of the HIT sessions were conducted as classic style on roller skies or on snow, or uphill running.

Training volume and intensity were calculated based on the subjects’ own heart rate monitors. All subjects wrote down their daily training volume and intensity on the Norwegian Olympic system’s training diary, the Norwegian Biathlon Federation’s training diary or other training diaries as desired, and collected after the intervention period.
Table 4. The total training volume, in hours per week and total hours, during the 5 week intervention period for BP and TRAD group. The endurance training is divided into three heart rate zones of maximal heart rate (% of HF\textsubscript{max}): Zone 1: 60-82%, Zone 2: 83-87%, Zone 3: 88-100%. Other training can be strength training, speed training etc. Values are presented in mean ± SD.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>BP</td>
<td>TRAD</td>
<td>BP</td>
<td>TRAD</td>
<td>BP</td>
<td>TRAD</td>
</tr>
<tr>
<td>Zone 1</td>
<td>8.2 ± 4.7</td>
<td>11.2 ± 2.7</td>
<td>7.9 ± 2.6</td>
<td>12.9 ± 4.7</td>
<td>9.2 ± 2.9</td>
<td>9.6 ± 4.0</td>
</tr>
<tr>
<td>Zone 2</td>
<td>0.1 ± 0.1</td>
<td>0.1 ± 0.2</td>
<td>0.0 ± 0.0</td>
<td>0.3 ± 0.2</td>
<td>0.2 ± 0.3</td>
<td>0.2 ± 0.4</td>
</tr>
<tr>
<td>Zone 3</td>
<td>2.5 ± 0.2</td>
<td>1.1 ± 0.3</td>
<td>0.8 ± 0.4</td>
<td>1.3 ± 0.5</td>
<td>1.5 ± 0.5</td>
<td>1.0 ± 0.2</td>
</tr>
<tr>
<td>Other</td>
<td>0.9 ± 0.5</td>
<td>1.3 ± 1.0</td>
<td>1.4 ± 0.5</td>
<td>0.7 ± 0.8</td>
<td>2.1 ± 0.7</td>
<td>0.9 ± 1.0</td>
</tr>
<tr>
<td>Total</td>
<td>11.6 ± 4.4</td>
<td>13.8 ± 3.4</td>
<td>10.1 ± 2.8</td>
<td>15.1 ± 5.7</td>
<td>12.9 ± 2.8</td>
<td>11.6 ± 4.9</td>
</tr>
</tbody>
</table>
5.5 Testing

All tests were performed in the physiological laboratory (air conditioned room with temperature between 18-21 degrees C) at Lillehammer University College. The tests were conducted as skating technique V1 and/or V2. (In XC skiing, V1 is used in medium to steep uphill terrain, and V2 is used in flat to medium uphill terrain). The subjects could choose their preferred technique; some individual skiers prefer V1 and some V2, and the choice of V1 or V2 in uphill skiing for a group average does not influence O2-cost or performance (Losnegard et al. 2012). To ensure a minimum of variation of roller resistance, the same roller skis with standard wheels (Swenor, type-1 wheels, Sport Import AS, Sarpsborg, Norway) were used at pre- and posttests and the roller skies were pre-warmed for 15 minutes before each test while roller skiing on the treadmill. Carbon ski poles were used (CT3, Swix Sport, Lillehammer, Norway) and the ski pole were fitted each subject’s height. The subjects used their own ski boots. The pre- and posttests were conducted at around the same time of day (± 2 hours) for each subject to avoid influence of circadian rhythm. The subjects were told not to do any hard training the two days before the tests, and to follow the same procedures before both pre- and posttests. The participants did not take caffeine the last 3 hours before the tests, because caffeine can affect the blood pressure (Ragsdale et al. 2010; Whortley et al. 2010). All tests were performed by the same test-leader. (Note: These VO$_{2max}$ values will also be used by another thesis, see more in 5.10).

The same individual may have a different VO$_{2max}$ in different sports. Peak oxygen uptake (VO$_{2peak}$) is in fact specific to the type of activity. In reality, a trained athlete may have a VO$_{2peak}$ of 70 mL/kg/min in XC skiing, and have a VO$_{2max}$ at 80 mL/kg/min when running. This was the case for several of the XC skiers in the present study; they had a higher VO$_{2max}$ while running (personal communication). However, to obtain relevant and comparable values within a sport, the emphasis is to test VO$_{2max}$ in the activity specific mode. Runners do their VO$_{2max}$ testing when running; cyclists do their testing on cycle ergometer etc (Helgerud et al., 2007). In the present study, all VO$_{2peak}$ values will be presented as VO$_{2max}$ values, even though it is not the subject’s “real” VO$_{2max}$, but it is the the sport specific VO$_{2max}$.

5.6 Blood lactate profile test

The test starts with 15 minutes of warm up with roller skis on a treadmill (Lode Valiant Special, Lode B.V. Groningen, the Netherlands). The warm up speed for men were 13 km/h
with a 3% angle or 11 km/h, 2% angle for women. The test is an incremental test, with 5 minutes stages until a lactate level of 6 mmol/L is achieved. Each stage had the same speed, 10.8 km/h for men and 9 km/h for women. The first stage had a 5% angle, and at each continuous stage the angle was raised by 2% (5-7-9-11%). HR was measured during the test with Polar S610i HR monitor (Polar, Kempele, Finland). Blood samples were taken after each 5 min bout from a fingertip and were analyzed for whole blood [la] with Biosen C-line (EKF Diagnostic, Magdeburg, Germany).

VO₂ were measured the first 3.5 minutes of each bout, until a VO₂ steady-state condition. VO₂ were 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) were calibrated before the first test each day with a 3L, 5530 series, calibrated syringe (Hans Rudolph, Kansas City, MO, USA). Rate of perceived exertion (RPE) were recorded after every bout, using the Borg 6-20 scale (Borg 1982). (Note: Only SV- and Q values from the blood lactate profile test will be used in the present study, see more in 4.9).

SV and Q values were monitored continuously and measured during the blood lactate profile test using a bioimpedance method (Physio Flow, PF-05 Lab1, Manatec Biomedical, Paris, France). Peak SV values were calculated as the highest 30 second period during the blood lactate profile test, and SV and Q values were measured during the last 2 min of each stage. Mean values were used in statistics.

Physio Flow is a non-invasive hemodynamic monitor which can measure HR, SV and Q. The Physio Flow has been validated both on submaximal constant load and maximal incremental exercise (Richard et al. 2001; 2004; Lepretre et al. 2004). Studies have shown the device and method is valid on both maximal incremental tests and submaximal constant-load tests (Charloux et al. 2000; Richard et al. 2001; 2004).

The Physio Flow basically measures impedance changes (dZ) in response to electrical current from sets of electrodes (Ag/AgCl, Hewlett Packard 40493 E), one electrode transmitting and the other sensing. Two sets of electrodes are set above the supra-clavicular fossa at the left base of the neck and along the xiphoid (Figure 2, white/green and blue/black). Another set of
electrodes are used to monitor a single ECG (Figure 2, red/orange)

**Figure 2.** Electrodes’ placement. The electrodes are put on the upper body as in the figure. From the Physio Flow user manual

Q measurements by the Physio Flow device are calculated using the formula: \( Q = HR \times SVi \times BSA \), where \( Q \) is L/min, SVi is the SV index (mL/m\(^2\)) and BSA is the body surface area calculated using the formula by Haycock et al. (1978). HR is obtained from R-R intervals with the ECG first derive d(EGC)/d t. To calculate SVi, a calibration must be done based on 24 consecutive heartbeats while in resting condition before test start. This calibration finds the largest impedance (Z) variation during the systole (\( Z_{\text{max}} - Z_{\text{min}} \)) and the highest rate of variation of the impedance signal \((dZ/dt)_{\text{max}}\), named the contractility index. Further in the calculation, the SVi depends on the thoracic fluid inversion time (TFIT, in m/s), this is measured in the first derivative of the impedance signal (Figure 3) (Richard et al. 2004). During the tests/data collecting phase, the variations in the parameters were analyzed and compared by the Physio Flow device to what was found during the calibration phase/the baseline measurements. For more theoretical information about Physio Flow and how it calculates HR, SV and Q values, and on the device’s validity for exercise testing, see Charloux et al. (2000).
Figure 3. Waveforms found with the Physio Flow impedance device. The figure on top is the electrocardiogram (ECG), the middle and lower figures are impedance variations during the systole ($\Delta Z$) and the first derivative $dZ/dt$. Thoracic fluid inversion time (TFIT) and $dZ/\Delta t_{max}$ are shown on the lower figure.

5.7 Reproducibility test of the Physio Flow device

An unpublished study from 2011 at Lillehammer University College performed a reproducibility test on the Physio Flow device. Ten cyclists (Table 5) were recruited to do a blood lactate profile test on a cycle ergometer (Lode Excalibur Sport, Lode B. V. Groningen, the Netherlands). The test followed the procedures described in Rønnessad et al. (2012a), to summarize; the test started at 125 W for 5 minutes, and each new stage had a load that was 50 W higher and lasted 5 minutes. This was repeated until a [lactate] of 6 mmol/L was measured.
Blood was taken from a fingertip after each stage for lactate measurement. Two equal tests were performed with at a minimum of 2 and maximum of 5 days between each test. The procedures were the same before each test, and the subjects were told to train, eat and drink the same before each test.

Table 5. Subjects’ characteristics on the reproducibility test. Values are mean ± SD.

<table>
<thead>
<tr>
<th>Number</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>75 ± 4</td>
<td>181 ± 34</td>
<td>25 ± 3</td>
</tr>
</tbody>
</table>

The reproducibility test showed a good intra class correlation (ICC) for SV between test 1 and test 2. At 125 W the ICC was $r = 0.94$ ($P < 0.0001$), at 175 W it was $r = 0.94$ ($P < 0.0001$), at 225 W it was $r = 0.86$ ($P < 0.006$), and at 275 W it was $r = 0.93$ ($P < 0.001$) (Table 6). These results are in line with what have previously been found (Charloux et al. 2000; Richard et al. 2001; 2004), and it is concluded that the Physio Flow device has a good reproducibility while on a cycle ergometer. However, a reproducibility test has not been performed with the Physio Flow device during roller skiing on a treadmill. The main difference between the two is that there are more upper body movement during a roller ski test. The impact of more upper body movement on the Physio Flow is not clear.

Table 6. Reproducibility-test. Shows mean values ± SD for stroke volume (SV), cardiac output (Q) and heart rate (HR) at test 1 and test 2 on all stages for each subject. The coefficient of variation on each load is shown for SV, Q and HR. Intra class correlation is shown for SV. (This table is taken directly from an unpublished study from 2011 at Lillehammer University College).

<table>
<thead>
<tr>
<th>Load</th>
<th>SV 1 (ml·beat⁻¹)</th>
<th>SV 2 (ml·beat⁻¹)</th>
<th>ICC</th>
<th>CV  (1·min⁻¹)</th>
<th>Q 1 (l·min⁻¹)</th>
<th>Q 2 (l·min⁻¹)</th>
<th>CV Q</th>
<th>HF 1 (slag·min⁻¹)</th>
<th>HF 2 (slag·min⁻¹)</th>
<th>CV HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>125W n=10</td>
<td>132 ± 14</td>
<td>135 ± 11</td>
<td>0.94</td>
<td>14.8 ± 1.5</td>
<td>15.4 ± 1.6</td>
<td>5.60 %</td>
<td></td>
<td>112 ± 12</td>
<td>113 ± 12</td>
<td>4.50 %</td>
</tr>
<tr>
<td>175W n=10</td>
<td>136 ± 15</td>
<td>143 ± 13</td>
<td>0.94</td>
<td>17.9 ± 2.3</td>
<td>18.6 ± 2.0</td>
<td>4.10 %</td>
<td></td>
<td>129 ± 12</td>
<td>129 ± 11</td>
<td>2.60 %</td>
</tr>
<tr>
<td>225W n=10</td>
<td>143 ± 17</td>
<td>148 ± 14</td>
<td>0.86</td>
<td>20.9 ± 2.1</td>
<td>21.7 ± 2.0</td>
<td>5.10 %</td>
<td></td>
<td>147 ± 11</td>
<td>144 ± 11</td>
<td>1.90 %</td>
</tr>
<tr>
<td>275W n=8</td>
<td>148 ± 19</td>
<td>155 ± 16</td>
<td>0.93</td>
<td>24.3 ± 2.0</td>
<td>24.9 ± 2.4</td>
<td>3.70 %</td>
<td></td>
<td>164 ± 13</td>
<td>161 ± 11</td>
<td>2.20 %</td>
</tr>
<tr>
<td>325W n=6</td>
<td>153 ± 21</td>
<td>156 ± 19</td>
<td>0.93</td>
<td>26.5 ± 3.1</td>
<td>26.5 ± 3.1</td>
<td>1.60 %</td>
<td></td>
<td>172 ± 6</td>
<td>168 ± 7</td>
<td>1.90 %</td>
</tr>
<tr>
<td>Mean</td>
<td>153 ± 21</td>
<td>156 ± 19</td>
<td>3.40</td>
<td>26.5 ± 3.1</td>
<td>26.5 ± 3.1</td>
<td>1.60 %</td>
<td></td>
<td>172 ± 6</td>
<td>168 ± 7</td>
<td>2.62 %</td>
</tr>
</tbody>
</table>

1 = test 1, 2 = test 2, HF = heart rate, ICC = intra class correlation, Q = cardiac output (L/min), n = number of subjects on each load. SV = stroke volume, CV = coefficient of variation, W = watt.

5.8 VO$_{2\text{max}}$ test

After the blood lactate profile test was over, the participants got 15 min active recovery before another incremental test for measuring VO$_{2\text{max}}$. The start speed for men was 10.8 km/h and 9
km/h for women. The incline started at 5 % and increased every minute with 2 % up to 15 % (7 – 9 – 11- 13 – 15), and then the speed were increased every minute by 0.5 km/h until exhaustion. VO$_{2\text{max}}$ were taken from the average of the two highest measurements. RER above 1.05 and skiing until exhaustion (RPE < 18) were used as criteria to ensure VO$_{2\text{max}}$ were obtained. VO$_{2\text{max}}$ values and time to exhaustion in this test were used as performance measurement. (Note: After the 15 min recovery period between the blood lactate profile test and the VO$_{2\text{max}}$ test, the Physio Flow systematically shut down. No SV or Q measurements were collected from the VO$_{2\text{max}}$ test).

5.9 Statistical analyses

All the values that are presented in the text, tables and figures are mean ± standard deviation (SD). Mean effect size (ES), were calculated as Cohen’s d, to see any practical significance while comparing performance improvements among the groups (Hopkins 2000). The criteria to interpret the magnitude of 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. Unpaired Student t-tests were used on differences between groups at baseline performance and training volume between the groups (Excel 2010; Microsoft Corporation, Redmond, WA, USA). Paired Student t-tests were used on pre- and post-measurements on VO$_{2\text{max}}$, time to exhaustion and SV measurements. Differences between the groups from pre- to post- testing, unpaired Students t-tests were used. P < 0.05 are considered statistical significant.

5.10 Sharing of data

All the data collected for this study (1), is the same data collected for another study (2). Studies 1 and 2 have been cooperated in recruiting subjects and collecting all the data. However, after the data collection, the authors have individually written their own thesis. No cooperation has been done during the writing process. Studies 1 and 2 have shared all the results from the data collection, meaning that the results presented in the present study are only a handful of all the results collected. That is, the studies 1 and 2 focus on different data. To sum the data included in the present paper:

- VO$_{2\text{max}}$ measurements (from the VO$_{2\text{max}}$ -test, study 2 will also use the same VO$_{2\text{max}}$ measurements)
- SV and Q measurements (from the blood lactate profile test, only this study)
- Time to exhaustion (from the VO$_{2\text{max}}$ –test, only this study)
In addition, these are some examples of other data that were collected: Watt$_{\text{max}}$ from the VO$_{2\text{max}}$-test, O$_2$ cost-values, RER-values, HR-values, [la$']$-values, power at 4 mmol/L, (and generally more about lactate threshold and work economy changes) from the blood lactate profile test. Finally, a “20-minutes-all-out performance test” was performed.
6.0 Results

6.1 Baseline

There were no significant differences between BP group and TRAD group before the training intervention period on body mass, body height, age, BMI, \( VO_{2\text{max}} \), time to exhaustion, SV (mL/beat/kg) or Q (L/min/kg).

6.2 \( VO_{2\text{max}} \) test

The BP group increased relative \( VO_{2\text{max}} \) (mL/kg/min) from pre- to posttest (2.6 ± 3.6%, \( P < 0.05 \)) and absolute \( VO_{2\text{max}} \) (L/min) (2.0 ± 2.5%, \( P < 0.05 \)). The TRAD group had no statistical significant change in relative or absolute \( VO_{2\text{max}} \) (0.8 ± 3.5% and –0.1 ± 3.0% respectively). There was no significant difference between the two groups in either relative or absolute changes (Figure 4 and 5). Mean ES of the relative improvement in \( VO_{2\text{max}} \) (mL/kg/min) and absolute improvement in \( VO_{2\text{max}} \) (mL/min) revealed small to moderate effects of performing BP training vs. TRAD training (ES = 0.51 and ES = 0.75 respectively).

![Figure 4. Maximal oxygen consumption (\( VO_{2\text{max}} \), mL/kg/min) at pre- and post tests for all the individual participants in the block periodization group (BP) and the traditional periodization group (TRAD). # significantly larger at posttest than at pretest (\( P < 0.05 \)).](image-url)
Figure 5. Maximal oxygen consumption (VO₂max, mL/min) at pre- and post tests for all the individual participants in the block periodization group (BP) and the traditional periodization group (TRAD). # significantly larger at posttest than at pretest (P < 0.05).

6.3 Time to exhaustion

The BP group had a statistically significant increase in the time to exhaustion on the VO₂max test (6.1 ± 6.4%, P < 0.01). The TRAD group had no change (-2.0 ± 7.7 %). Mean ES of the relative improvement in time to exhaustion revealed a moderate effect of performing BP training vs. TRAD training (ES = 1.14). For the BP group the average at pretest was 390 ± 61 seconds, and at posttest 411 ± 49 seconds. For the TRAD group the average at pretest was 411 ± 45 seconds, and posttest at 403 ± 49 seconds.
Figure 6. Percentage change in time to exhaustion on the VO₂max-test at posttest compared to pretest, for the block periodization group (BP) and the traditional periodization group (TRAD). Values are mean ± SD. # significantly different from pre- to post testing.

6.4 SV and Q values

SV peak (mL/beat) (from the blood lactate profile test) for BP group at pre- and posttest was 139 ± 27 and 131 ± 22, respectively, and 154 ± 19 and 148 ± 18 for TRAD group. No significant differences were seen from pre- to posttest in any group, and no differences between the groups were seen.

Mean SV (mL/beat/kg) (from the stages with 5%, 7% and 9% angel on the blood lactate profile test) did not change from pre- to posttest in BP group (pretest 1.89, 1.92 and 1.99; posttest: 1.72, 1.79, 1.85), or in TRAD group (pretest: 2.0, 2.04, 2.10; posttest: 1.98, 1.99, 2.02) (Figure 7). No significant differences between the groups were seen. This was also the case using Q (mL/min/kg) values (Figure 8) where BP group (pretest: 0.27, 0.30, 0.34; posttest: 0.24, 0.28, 0.31) had no changes and the TRAD group (pretest: 0.29, 0.32, 0.34; posttest: 0.26, 0.31, 0.34) had no changes. No differences were seen between the two groups.

The SV (mL/beat) did not plateau during the blood lactate profile test in the BP group at pre- or posttest. The BP group came up to an intensity of 92% of HRmax and 91% of VO₂max at both tests. In the TRAD group, no plateau was seen during pre- or posttest, the group reached an intensity of 92% of HRmax and 93% of VO₂max in both tests.
Figure 7. The evolution of stroke volume (SV, mL/beat/kg) according to the percentage of maximal heart rate (% of HR_{max}) for the block periodization (BP) group and the traditional periodization (TRAD) group. No significant changes were observed between the two groups.

Figure 8. The evolution of cardiac output (Q, L/min/kg) according to the percentage of maximal heart rate (% of HR_{max}) for the block periodization (BP) group and the traditional periodization (TRAD) group. No significant changes were observed between the two groups.
7.0 Discussion

The main finding of the present study was that short time BP of endurance training had small to moderate effect on endurance performance indices compared to TRAD. During a five week period, the BP group was able to improve VO$_{2\text{max}}$ and time to exhaustion at VO$_{2\text{max}}$-test in trained XC skiers and biathletes. The TRAD group showed no significant changes in these parameters.

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

The ~3% statistical significant increase in relative VO$_{2\text{max}}$ after HIT is in line with, but is slightly lower than in other studies (Breil et al 2010, Rønnestad et al. 2012$^a$; Rønnestad et al. 2012$^b$). Breil et al. (2010) observed a 6% improvement in VO$_{2\text{max}}$ after an 11 day HIT block containing 15 HIT sessions in alpinists. However, the control group in this study had not the same amount of HIT during the intervention period, making it difficult to tell if the increase was due to the extra large volume of HIT or the organization of the training.

Rønnestad et al. (2012$^a$) observed a ~5% increase in relative VO$_{2\text{max}}$ in the BP group in trained cyclists and no changes in the control group. This was found despite similar volumes of HIT and LIT during a four week intervention period, where the BP group had a 5-1-1-1 HIT program. Another study had a 12 week training intervention period, where 8 trained cyclists who performed BP improved relative VO$_{2\text{max}}$ by ~9%. This study had also similar volumes of HIT and LIT. The increase in VO$_{2\text{max}}$ was likely to be related to an increase in Hb$_{\text{mass}}$ which was observed in this BP group (Rønnestad et al. 2012$^b$).

Mean effect size in the present study of the relative and absolute improvements in VO$_{2\text{max}}$ showed a small to moderate effect of performing BP training vs. TRAD training (ES = 0.51 and ES = 0.75 respectively). Rønnestad et al., (2012$^a$) observed a large effect (ES = 1.34) in relative improvements in VO$_{2\text{max}}$.

Rønnestad et al. (2012$^a$) explained the increase in VO$_{2\text{max}}$ using BP, the higher Hb$_{\text{mass}}$ seen in their BP group. Helgerud et al. (2007) found that the increase in VO$_{2\text{max}}$ corresponded to the changes in SV$_{\text{max}}$; the same did Macpherson et al. (2010), the increase in VO$_{2\text{max}}$ was due to
increase in $Q_{\text{max}}$ because of an increase in SV. As will be discussed later, the SV or Q did not increase from pre- to post testing in the present study.

Peripherally, an increase in VO$_{2\text{max}}$ is due to an increase in a-v O$_2$ difference. A larger a-v O$_2$ difference comes from a better blood flow distribution, higher capillary density, local enzymatic adaptations, and higher mitochondrial density (Blomquist & Saltin 1983; Daussin et al. 2007). None of these parameters were tested in the present study.

It is known that HIT activates important signaling pathways involved in mitochondrial biogenesis. Daussin et al. (2008) found that only high and fluctuating workload and O$_2$ uptake during HIT improve muscle mitochondrial function, which is crucial in increasing VO$_{2\text{max}}$ and Q. This can indicate that HIT may be an effective way to stimulate a higher volume of muscle mitochondria.

### 7.2 Time to exhaustion

When looking at the time to exhaustion results, the BP group had a statistical significant increase in performance by ~6%. This parameter shows that a performance improvement did occur in the BP group, while no significant changes occurred in TRAD (~ -2%).

The TRAD group in the present study did not have any improvements in VO$_{2\text{max}}$ or time to exhaustion. Likewise, Nimmerichter et al., (2012) used 6 x 5 min interval bouts two times per week for 4 weeks, and did not find any changes in VO$_{2\text{max}}$. It might be that the TRAD group needs a longer training intervention period to show performance improvements.

Garcia Pallares et al., (2010) found that BP can be an effective way to organize training. In world class kayakers they found the same VO$_{2\text{max}}$ gains as the TRAD group, but the BP group had a 10 week/120 hours shorter training cycle than the TRAD group, suggesting BP training to be more effective than TRAD training for improving performance in highly trained athletes.

The use of time to exhaustion tests is commonly used as a performance test in studies, so is time trial exercise tests. However, there has been found greater variability on time to exhaustion tests than time trial tests, questioning the reliability of the time to exhaustion tests as a performance indicator (Hinckson & Hopkins, 2005; Laursen et al. 2007). Time trials have
a better validity than time to exhaustion tests because the time trials provide a good physiological simulation of actual performance, and it correlates with actual performance (Currell & Jeukendrup 2008). Costa et al. (2011) found that competitive cyclists exercised longer at their VO\textsubscript{2max} on a time to exhaustion test the second time compared to the first test. HR values, blood lactate levels and VO\textsubscript{2} measurements were constant between the tests, suggesting the better performance came from the cyclists’ psychology. The subjects’ psychology in the BP group cannot be ruled out for explaining the performance improvement in the present study, however the group did have a VO\textsubscript{2max} increase as well, but the TRAD group did not have any increase in either time to exhaustion or VO\textsubscript{2max}, suggesting there was a real performance improvement in the BP group compared to the TRAD group in the present study.

### 7.3 SV and Q

No changes were seen on SV or Q values from pre- to post test in BP or TRAD group. There were no significant differences between the two groups. When looking at Figure 7 and 8, it seems that the TRAD group had a higher SV (mL/beat/kg) during both pre- and post test than the BP group. However, both groups had the same change from pre- to post test. This “tendency” of a higher SV in TRAD group, might be explained by the small weight difference between the two groups (not significant) or genetic variations. There was also a “tendency” for both the BP and TRAD group having lower SV and Q values at post test compared to pre test. These changes were not significant, and might be explained by methodological weaknesses (the fluid balance was not well enough standardized at each test).

The SV did not plateau during the blood lactate profile test in the BP or TRAD group at pre- or post test. The BP group stopped at an intensity of 91% of VO\textsubscript{2max}, and the TRAD stopped at an intensity of 93% of VO\textsubscript{2max} in both tests. It is accepted that SV increases in all individuals from rest to light exercise. It has also been shown that SV does not increase further when reaching 40 % of VO\textsubscript{2max} in untrained subjects (Åstrand et al. 1964). Zhou et al. (2001) found that in untrained and trained university students, SV did not increase after moderate exercise. However, elite distance runners continued to increase SV up to maximal exercise with no plateau. Gledhill et al. (1994) found the same results, with no plateau of SV up to maximal exercise in elite cyclists. The present findings are in line with Zhou et al. (2001) and Gledhill et al. (1994). The trained XC skiers in both groups did not reach a plateau
in SV during the blood lactate profile test, however, it must be pointed that the test was not designed so that the participants could reach maximal exercise.

What would have happened with the SV development from 93% of VO$_{2\text{max}}$ up to VO$_{2\text{max}}$ is not clear. As mentioned, there are no SV and Q measurements on the VO$_{2\text{max}}$ test, because of a Physio Flow malfunction. Why it did not work, is unclear. It might be that an altered fluid balance after the blood lactate profile test affected the blood pressure, which in turn affected the Physio Flow device. This is a methodological weakness.

7.4 Training

Other studies found a higher increase in physiological parameters for the BP group than the present study did (Garcia-Pallares et al. 2010; Breil et al., 2010; Rønnestad et al. 2012$^a$; 2012$^b$).

The present study began in the start of the XC skiers and biathletes’ competition period (November). The Rønnestad et al. (2012$^a$) study started during the cyclists preparation phase, after a longer "active recovery period". The self reported training per week in the last four weeks prior to the present study showed that the BP group had 13 ± 3.5 hours of endurance training with 1.0 hour in Zone 3. Rønnestad et al. (2012$^a$) had a self reported amount of 9 ± 3 hours of LIT, and no HIT (0 hour in Zone 3) per week in the BP group the last two months leading up to the training intervention. Presumably, the participants in the present study were already in a good performance shape, maybe in contrast to the participants in the other study who had not performed any HIT sessions the last two months. Seiler & Tønnessen (2009), found that the subjects who reported no weekly intervals the last two months before an interval training intervention study, achieved higher average improvements on VO$_{2\text{peak}}$ and tended to achieved higher average improvements on power at VO$_{2\text{peak}}$ compared to subjects reporting one or more intervals per week. It might seem that it is harder to develop further performance enhancement in individuals who already are in a good competition shape vs. after a longer off-season period.

However, studies on seasonal variations in VO$_{2\text{max}}$ have found various results. Ingjer (1991) found that elite XC skiers in the 1980s had significantly higher VO$_{2\text{max}}$ during the competition period, compared to the early preparation phase (5-10%). This has also been seen in elite runners and cyclists (Svedenhag & Sjodin 1985; Zapico et al. 2007). Other studies have not
found any changes in seasonal VO$_{2\text{max}}$ on XC skiers (Evertsen et al. 1999; Losnegard et al. 2013), or in cyclists (Lagaz Arrese et al. 2005). On the other hand, most studies that found no seasonal variation in VO$_{2\text{max}}$ did see an increase in performance from early preparation phase to the competition period (Evertsen et al. 1999; Lagaz Arrese et al. 2005; Losnegard et al. 2013). Losnegard et al. (2013) followed a group of high-level XC skiers through more than a year and concluded that training-induced changes in VO$_{2\text{max}}$ will take more than one year to develop, and that VO$_{2\text{max}}$ changes not will be reflected during only one season. However, an increase in performance was seen from early preparation period to the competition season despite no changes in VO$_{2\text{max}}$.

The subjects in the present study had 30 minutes of work in Zone 3 in every HIT session, either performing 5x6 min or 6x5 min intervals. Seiler et al., (2013), found that 4 x 8 (32 min working at 90 % HR$_{\text{max}}$) intervals gave greater overall gains in VO$_{2\text{max}}$ compared to 4 x 4 (16 min working at 94 % HR$_{\text{max}}$) intervals or 4 x 16 (64 min working at 88 % HR$_{\text{max}}$) intervals. The study concluded that accumulating 32 minutes at an intensity of 90 % HR$_{\text{max}}$ is effective in increasing VO$_{2\text{max}}$. This suggests the intervals performed in the present study were well optimized for increasing VO$_{2\text{max}}$.

The subjects in both groups followed the training program quite precisely. The endurance training was close to polarized, except for a planned decrease in Zone 2 training. Both groups followed the suggested training characteristics of elite endurance athletes in XC skiing and other different sports (Seiler & Kjerland 2006). The small differences in training hours between the BP group and TRAD group in Zone 2 and 3 (Table 3) is likely due to different approaches writing the training diaries. The subjects were not told especially how to write the HIT training into the training diaries. This led to that some subjects reported the interval training as 30 min in Zone 3, regardless of their actual HR, and some subjects reported what the HR monitor had stored. (For example, some reported the 30 min interval as 24 min in Zone 3 and 6 min in Zone 2, because it takes some time at each interval bout to reach the correct HR zone). This uncertainty in the reporting was a methodological weakness. For future studies, this uncertainty should be avoided. However, no significant differences were seen in total volumes of LIT or HIT between BP group and TRAD group, concluding the performed training was similar in the two groups during the training intervention period.
The participants organized their HIT sessions as it suite them, the researchers did not participate or control the HIT sessions. The HIT sessions were not followed by any researcher, so 100% control of the quality etc. of each session is hard to determine. For future studies, the HIT sessions might be organized differently, having joint sessions where all participants participate and train together. However, XC skiers and biathletes are used to training alone or in smaller groups, so the quality of each HIT is believed to have been high.

### 7.5 HIT and LIT to increase performance

It is well known how important HIT is on performance and physiological factors (Laursen & Jenkins 2002), but athletes have a limit on how much HIT they are able to perform (Billat et al. 1999). In well trained athletes, who already have a high load of LIT, supplementations of HIT sessions are extremely effective on performance (Laursen 2010). 6-8 HIT sessions over 2-4 weeks can increase endurance performance of 2-4% in well trained athletes (Laursen 2012; Laursen & Jenkins 2002).

The importance of LIT is less discussed in research articles, but high volumes of LIT are likely to contribute to a high skeletal muscle energy status, an ability to sustain high power outputs for a long time, and a better ability to recovery from HIT sessions (Seiler et al. 2007; Laursen 2010), and a higher increase in capillary density has been seen in LIT compared to HIT in untrained subjects (Daussin et al. 2007), so LIT cannot be ruled out in increasing performance because it induces important metabolic adaptations. However, studies on untrained subjects make the results hard to generalize to trained athletes.

The efficiency of LIT has been indicated in some studies in trained athletes. Fiskerstrand & Seiler (2004) retrospectively studied training changes in elite Norwegian rowers from 1970-2001. \( \text{VO}_{2\text{max}} \) was increased with 12 %, and a 6 minute rowing ergometer performance was increased with 10 % from 1970s to the 1990s. In the whole period, the LIT was increased (30 to 50 hrs/month) and supramaximal sprinting (23 to 7 hrs/month) was decreased. The total training volume increased by 20 % in the period (924 to 1128 hrs/month), and the performance results were improved (Fiskerstrand & Seiler 2004). Another study found that the time spent training at intensities below the first ventilator threshold (Zone 1), had strong relationships with 4 km and 10 km running performance in eight sub elite endurance runners (Esteve-Lanao et al. 2007). However, both the BP group and TRAD group in the present
study had similar volumes of LIT during the training intervention, making it difficult to suggest LIT alone can explain the BP group’s increase in VO$_{2\text{max}}$.

The studies mentioned show the importance of combining both HIT and LIT into training programs, for maximal performance. It has been demonstrated that both LIT and HIT or a combination of both induce a higher mitochondrial oxidative capacity, higher capillary density, improved fat oxidation potential and increases glucose transport capacity in the skeletal muscle of endurance athletes. All of this results in a better capacity to generate ATP aerobically, which is extremely important for endurance performance (Laursen 2010).

We can see from all this documentation that it is important to have periods of both HIT and LIT at the appropriate time in a training program, all to get an optimal increase in endurance performance. The art is to combine periods of high volumes of LIT with hard phases of HIT, and also get enough recovery (Issurin 2008). It is important to have a balance between HIT and LIT, and training and recovery. When phases of high training volumes are repeated with no or not enough recovery, and the autonomic balance is repeatedly too much disturbed over time, it could result in over training (Billat et al. 1999).

**7.6 Inter-individual variability**

Inter-individual variability in relative VO$_{2\text{max}}$ ranges from -2% to 10% in the BP group in the present study. The Heritage Family Study (Wilmore et al. 2001), showed that training induced changes to VO$_{2\text{max}}$ varied extensively between individuals. When subjects had similar training stimulus, and followed the same training protocol, the average VO$_{2\text{max}}$ gain was 19%, but 5% had no change in VO$_{2\text{max}}$ at all, and another 5% had a VO$_{2\text{max}}$ gain up to near 50%. Even though training responses vary, 8 of 10 in the present study’s BP group had an increase in both absolute and relative VO$_{2\text{max}}$. In the TRAD group, 5 of 10 had an increase, suggesting the average increase using BP was real and had a physiological significance.

Different stressors; emotional, social, academic and dietary have been seen to decrease the immune system, decrease adaptations to training, decrease motor coordination, worsen hormonal status and cognitive performance. All these stressors may result in reduced physiological performance (Kiely 2012). Research suggests that adaptations to training vary extremely between individual athletes, even though they follow identical training interventions (Wilmore et al. 2001). An identical training session will make a unique training
response for the individual athlete, and a training intervention will also make a unique training response for each individual athlete taking part of the study. Therefore, group based results and observations may not be generalized to all individuals (Kiely 2012).

As seen in the present study, BP as a group increases their relative VO$_{2\text{max}}$ by $\sim$3%, but two of the participants in this group got a small decrease in VO$_{2\text{max}}$ after the BP training. Many of the subjects in the present study are young, hard working and determined to be elite skiers or biathletes. Most of them also study at Lillehammer University College. The first exam period in the school year is exactly at the same time as the competition season starts, and this research was done during exactly this period. The impacts of this on our subjects are unknown; no one reported negative effects of academic work or other such stressors. The groups in the present study were matched to eliminate an unbalance in such stressors. There are equal students vs. not students in each group, there are almost equal numbers of girls in each group and both groups have the same number of older army athletes.

7.7 Periodization

Kiely (2012) suggest that periodization of training is a good thing, but we should not forget that variation is a necessary component of effective training. Training monotony (lack of variation) may induce increased overtraining syndromes, poor performance and a higher risk of infections and sickness (Smith 2003; Kiely 2012). And opposite; decrease in training monotony has been associated with personal best performances (Kellmann 2002). However, if stimuli are excessively varied, if too many multiple training targets are focused on at the same time, progress might be slow or nonexistent (Kiely 2012). So, training planning has to balance variation, and focus on further increase well developed physiological performance.

This is where block periodization comes in the picture. Traditional training organization focuses on developing too many abilities; the variation might be too high, leading to suboptimal stimulus and suboptimal adaptations (Issurin, 2008; 2010). In block periodization, the variation is still high, but in short microcycle periods, using block periodization the focus is on few selected abilities, enabling a heavier training stimulus (Issurin 2008; 2010).

The better trained the athletes are, the larger stimulus of HIT are needed to further improve the performance (Issurin 2008; 2010). In the present study, the same volume of HIT was
performed in both groups, and it might be that the concentrated blocks of HIT gave the favorable adaptations in the trained athletes. HIT give peaks of training stimulus, and the larger stimuli of HIT during a HIT block may be likely to explain the increased performance in the BP group. Block periodization might actually be necessary for top athletes to further improve their performances.

8.0 Summary

The present study indicates that organizing the endurance training in XC skiers and biathletes with block periodization training, having 5-1-3-1-1 HIT sessions and a general focus on low intensity training during a five week intervention period, give better adaptations compared to organizing the endurance training with traditional periodization training, having 2-2-3-2-2 HIT session interspersed with low intensity training. Improvements in VO$_{2\text{max}}$ and time to exhaustion were seen in the BP group, but not in the TRAD group. The ES of the relative improvement of these parameters, revealed a moderate effect of performing BP training vs. TRAD training. This effect was seen despite both groups had similar total volumes of HIT and LIT during the five week intervention period. No changes or differences were seen in SV or Q measurements.
References


Losnegard T., Myklebust H, & Hallen J. (2013). Seasonal variations in VO2max, O2-cost, O2 deficit and performance in elite cross-country skiers. *Journal of Strength and Conditioning research.* (Accepted) (From doctorate)


Appendix I

Significance of the study

The knowledge expected from this study is highly practical and applicable knowledge. Knowing how to, in the best way possible, organize training (and especially high intensity training) is very important, not only for elite athletes, but also for amateurs that do not have so much time for training. Elite athletes will train as efficient as possible, or get the maximum effect out of every training session/day/week. To accomplish this, it is important to have an understanding how to organize high intensity training. If this research can contribute to a broader understanding of how to organize training sessions, the author will be happy. High intensity training does improve VO$_2$max; the key is to find the correct balance between a high training stimulus and sufficient recovery. Maybe the training planning in the cross country skiing and the biathlon environment will change to a more block periodization specific method.

Limitations and conflict of interest

To check how the VO$_2$max is developing throughout the training intervention period, it would have been interesting to have a VO$_2$max test after each week. This was not done in the present study, and hopes are for this to happen in future studies. Unfortunately, the SV (and Q) was not measured during the VO$_2$max-tests. There were limitations on the use of the Physio Flow device. Hopes are for future studies to measure SV all the way up to maximal exercise. There is no conflict of interest.

Appendix II

Literature search

Aim, objectives and hypotheses

The overall aim is to develop a broader understanding on how to optimize the organization of aerobic training programs, and especially how to better organize HIT and LIT to give an optimum endurance performance progress.

The present study measures what happens to VO$_2$max and cardiac output adaptations in two different training groups. A time to exhaustion test will compare performance development. One group will do traditional training and the other block periodization training.
1. Will the use of block periodization training give a better improvement in VO\(_{2\text{max}}\) adaptation than traditional periodization training?
   We hypothesize that both groups will increase VO\(_{2\text{max}}\), but the block periodization training group will increase VO\(_{2\text{max}}\) significantly more than the traditional periodization training group.

2. Will the time to exhaustion increase during the training intervention period?
   We hypothesize that both groups will increase time to exhaustion, but the block periodization training group will increase time to exhaustion significantly more than the traditional periodization training group.

3. Will the SV and Q values change during the training intervention period? When will the SV plateau?
   We hypothesize that peak SV, and mean SV and Q will increase in the block periodization group, and no changes will occur in the traditional periodization training group.
   We hypothesize that SV will plateau at the same level for both groups before and after the training intervention period.

**Which keywords have been used in the study?**

| Keywords used: | Block periodization, traditional periodization, stroke volume, stroke volume and VO2max, stroke volume does not plateau, Physio Flow, time to exhaustion, non-invasive, blood pressure, fluid balance, interval, interval training, high intensity interval training, high intensity training, endurance performance, low intensity training, training intensity, cross-country skiers, maximal oxygen uptake |

**Where have you search for articles:**

| PubMed  | Google Scholar |

**Searches that gave relevant results:**

| PubMed: Block periodization, traditional periodization, high intensity interval training, cross-country skiers, | Google Scholar: Stroke volume, stroke volume does not plateau, Physio Flow, high intensity training, block periodization, traditional periodization, |

**Comments:**

Several articles were found via “related articles”, supervisor suggested articles, articles were known from previous studies,