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Abstract

Previous studies have found block periodization to be an effective training organization model for improving endurance performance indicators as well as related physiological capacities in endurance athletes. Some research also indicates that block periodization is superior compared to traditional periodization for improving the aforementioned variables among endurance athletes. However, these studies investigated the effect of using block periodization of high-intensity training, while no studies so far have compared systematic block periodization of both low-, moderate-, and high-intensity training with traditional periodization. Therefore, the aim of the present study was to investigate whether systematic block periodization (BLOCK) is more effective in improving cycling performance and physiological performance-determining variables compared to traditional periodization (TRAD) among well-trained cyclists during the preparatory period. 25 well-trained male cyclists (VO_{2max}: TRAD 60.2 ± 8.0 ml·kg^{-1}·min^{-1}, BLOCK 56.8 ± 7.2 ml·kg^{-1}·min^{-1}) were assigned to a 12-week TRAD or BLOCK program, where both groups performed the same overall volume of low-, moderate-, and high-intensity training. Average 40-minute time trial power (W_{40TT}), maximal oxygen uptake (VO_{2max}), power output at 4 mmol/L blood lactate (W_{4mmol}), cycling efficiency, and average peak power output (W_{peak}) were measured before, 4 weeks in, and after the 12-week training intervention. Both groups improved their VO_{2max} ($2.8 \pm 2.0\%$ vs $2.6 \pm 0.9\%$, W_{4mmol} ($8.6 \pm 11.6\%$ vs $7.6 \pm 4.1\%$), W_{peak} ($7.8 \pm 2.0\%$ vs $8.0 \pm 2.0\%$), and W_{40TT} ($5.2 \pm 0.4\%$ vs $5.7 \pm 0.0\%$) following the training intervention, but no significant differences ($P > 0.05$) between the groups were found. The present study concludes that BLOCK and TRAD seems to have the same effectiveness in improving cycling performance and associated physiological determinants in well-trained cyclists during the preparatory period.

Acknowledgements

Contents

1. Introduction

<u>1.1 Demands of Road Cycling</u>

Road cycling races are performed individually or as part of a team, and they consist of several formats, including one-day races and multi-day stage tours. The races typically last 1-5 hours and road cyclists are often required to ride on both flat roads and roads with steep inclines. Given that 95% of the energy for mechanical work is created aerobically for exercise longer than 30 minutes [1] road cycling is predominantly an aerobic capacity-oriented sport. However, the high power outputs required for mass starts, steep climbs, time trials, breakaways and the race finish rely heavily on producing ATP anaerobically. Descriptive studies on 3-week tour races have reported that 7% of any tour stage is spent above the anaerobic threshold [2, 3]. What can be taken from this finding is that cyclists need to train both their aerobic and anaerobic capacity in order to perform well in races.

<u>1.2 Physiological Determinants of Cycling Performance</u>

1.2.1   Maximum Oxygen Uptake

Maximum oxygen uptake (VO_{2max}) represents the maximum amount of oxygen that can be inspired and utilized. VO_{2max} can be calculated using the following equation: $VO_{2max} = Q \bullet$ a-vO_{2diff}, where Q refers to cardiac output (the product of heart rate and stroke volume) and a-vO_{2diff} refers to the difference between the O_2 saturation of arterial blood and mixed venous blood. Between Q and a-vO_{2diff}, Q is found to be the main factor distinguishing VO_{2max} differences between individuals at different performance levels [4-8] and is thought to contribute to up to 75% of VO_{2max} [9]. VO_{2max} has been considered the greatest factor in predicting athletic endurance performance [10, 11]. A high VO_{2max} is an important physiological attribute for a road cyclist to possess because it sets the upper limit for steady-state VO_2 and the lactate threshold [12]. In other words, a cyclist with a higher VO_{2max} can maintain a higher power output than a cyclist with a lower VO_{2max} because of a higher lactate threshold.

1.2.2 Efficiency

Efficiency is the ratio between work output and energy input, and is commonly used to express energy expenditure [13]. It determines how much speed or power can be generated from a given VO_2 [12]. Two variables that affect efficiency in cycling are work rate and cadence, in which work rate accounts for more than 90% of the variability [13]. The percentage of type I muscle fibers may also determine efficiency, as some but not all studies have found strong correlations between cycling efficiency and percentage of Type 1 muscles fibers in the vastus lateralis [14, 15].

Efficiency is considered a great predictor of performance in individuals with similar VO_{2max} values [16]. Small improvements in efficiency may lead to major improvements in cycling [17]. Theoretical modelling suggests that a 1% improvement in cycling efficiency could lead to a 48 s improvement in 40 km time-trial time in an elite cyclist [18]. Improved efficiency can be advantageous as an efficient cyclist will be able to cycle faster and at higher power outputs than a less efficient one while expending the same amount of energy.

Although efficiency is considered a predictor of performance in cycling, results from studies remain inconclusive concerning whether endurance training improves efficiency [15]. Most studies seem to suggest that endurance training cannot improve efficiency, but it is likely that most of these studies performed a type II error due to methodological errors [19]. However, strength training appears to have a positive effect. Sunde et al. [20] found a 5% improvement in efficiency in competitive cyclists who underwent 4x4RM half-squats three times a week for 8 weeks.

1.2.3 Lactate Threshold

The lactate threshold (LT) or anaerobic threshold is the point at which blood lactate concentration begins to accumulate sharply during exercise. It is often expressed as the percentage of VO_{2max} or power output at LT ($\%VO_{2max}$ or W_{LT}) [21]. Increased lactate production is considered an indicator of anaerobic glycolysis and an increased reliance on anaerobic metabolism to meet energy demands. The increased reliance on anaerobic metabolism causes a rise in blood lactate and fatigue [21]. LT is an important endurance

factor because it determines the maximum steady-state power output that can be sustained for an extended period [22, 23]. LT expressed as velocity and power output strongly correlates to endurance performance [4, 24-26]. Several studies have found moderate to high correlations between LT_w and time trial performances ranging from 5 to 90 minutes in length [24, 27]. This finding is understandable as power output at LT expresses the combined effects of VO_{2max} and economy/efficiency, both of which are separately related to performance [28].

1.3 <u>Performance Indicators</u>

In addition to physiological determinants of performance, there are several performance indicators that are considered important for predicting and monitoring cycling performance. One such performance variable is peak power output (W_{peak}), defined as the maximum power output sustained during the last minute of a progressive exercise test to exhaustion [29]. W_{peak} can be determined using the VO_2, O_2 deficit and gross efficiency of the last minute of a progressive exercise test to exhaustion by the following equation: ($VO_2 + O_2$ deficit) x gross mechanical efficiency, in which VO_2 is determined by VO_{2max} and the LT, and O_2 deficit is determined by total buffering capacity [12]. Significantly high correlations have been found between W_{peak} and cycling time trial performance (flat) ranging from 16 to 40 km [27, 30, 31] and seem to explain around 80% of the variance in performance among subjects with similar VO_{2max} levels [27, 31]. The association between W_{peak} and cycling performance is slightly lower for uphill and rolling terrain conditions, but becomes similar to flat conditions when presented relative to body mass (W/kg) [32]. It has also been observed that W_{peak} is a stronger predictor of performance for longer time trials, with Bentley et al. [27] finding a considerably higher correlation between W_{peak} and average W for 90-minute time trials versus the correlation for 20-minute time trials. W_{peak} appears to distinguish well-trained cyclists from professional cyclists, making it a well-suited predictor of cycling performance [33]. The reason that W_{peak} is a strong predictor of cycling performance is that many other predictors of cycling performance influence W_{peak} as shown in the earlier equation.

Apart from W_{peak}, mean power output during time trials has been used as an indicator of cycling performance [34]. Time trial protocols have subjects ride at a self-selected intensity for either a set distance or set duration. The 40km time trial is the most commonly used in research, but many other time trial distances and durations have been used [34]. Time trials

have been considered the most reliable and ecologically valid protocol to predict competitive performance and to track the effects of training interventions on aerobic endurance of road cyclists [35]. Additionally, time trial performance variables (e.g. power output and time to complete the distance/work) have shown high correlations with aerobic endurance indices measured during incremental tests in time trials ranging from 3 to 100 kilometres [36], and have demonstrated sensitivity to detect small but meaningful changes in performance [37, 38].

1.4 Well-Trained Road Cyclists

Cyclists are categorized into levels based on their VO_{2max} and W_{peak} values in addition to their training patterns (Table 1). According to De Pauw et al. [39], cyclists can be categorized as sedentary, active, trained, well-trained, or professional. Well-trained road cyclists (WTCs) are characterized as cyclists who have a relative VO_{2max} of 65-71 mL•min^{-1}•kg^{-1} or an absolute peak power output of 380-440 watts and an average weekly training distance of more than 250 km [39]. The main differentiating factor between WTCs and professional level cyclists is training volume, in which professional cyclists train around double the distance per week [18]. Well-trained road cyclists are the group in focus in this study.

Table 1. Categorization Criteria of Road Cyclists

	PL 1	PL 2	PL 3	PL 4	PL 5
Physiological performance indicators					
1° relative VO_{2max}, mL · min^{-1} · kg^{-1}	<45	45–54.9	55–64.9	65–71	>71
2° absolute PPO, W	<280	280–319	320–379	380–440	>350
absolute VO_{2max}, L/min	<3.7	3.4–4.2	4.2–4.9	4.5–5.3	>5.0
relative PPO, W/kg	<4.0	3.6–4.5	4.6–5.5	4.9–6.4	>5.5
Cycling status					
training frequency/wk	—	—	≥3	>3	>5
training h/wk	<2–3	¾4	≥5	≥10	>10
training distance, km/wk (miles/wk)		<60 (<37)	60–290 (37–180)	>250 (>155)	>500 (>310)
cycling experience, y	—	—	—	≥3	≥5

Abbreviations: VO_{2max}, maximal oxygen uptake; PPO, peak power output; W, watts; PL 1, sedentary; PL 2, active; PL 3, trained; PL 4, well-trained; PL 5 professional. Taken from De Pauw et al. [39].

1.5 Training Intensities

Improving the physiological and performance variables previously mentioned requires training. Endurance training can be characterized by the intensity of the training as low-intensity training (LIT), moderate-intensity training (MIT), high-intensity training (HIT), and supramaximal training (SIT). Each of the intensities cause distinct physiological adaptations that can improve performance, although overlap can exist in the adaptations induced for the different intensities.

1.5.1 Low-Intensity Training (LIT)

LIT is training done below the first ventilatory threshold (VT_1), at 65-75% of VO_{2peak}, or at stable lactate concentrations of ≤ 2 mmol•L^{-1} [40]. It is usually performed as long duration, continuous exercise. LIT mainly taxes the aerobic energy system and predominantly recruits type I muscle fibers [41]. LIT sessions for WTCs are normally several hours in length and is an important aspect of training for cyclists. Long-term physiological adaptations that occur from LIT include increased capillarization, a greater percentage of type I muscle fibers, increased skeletal muscle mitochondrial content and oxidative enzyme function [42, 43]. LIT also increases fat oxidation as an energy source at submaximal intensities, thus preserving glycogen stores for high-intensity cycling [42] and increasing the threshold for lactate production [44]. These adaptations would enable cyclists to cycle at higher intensities for a longer duration without experiencing symptoms of fatigue [44]. High training volumes of LIT may also improve work economy/efficiency in trained endurance athletes over an extended period of time [45, 46]. LIT has been questioned as an effective training intensity by some researchers for inducing adaptation in already well-trained endurance athletes [47] .

1.5.2 Moderate-Intensity Training (MIT)

Moderate-intensity training refers to training done between 2-4 mmol•L^{-1} [29], a range that coincides with race intensity or slightly higher [48]. MIT is also commonly called threshold training, a reference to performing at or close to the LT and is performed as either continuous training or long interval training [40]. MIT stresses the body at a specific intensity and may

improve energy production from both aerobic and anaerobic metabolism. The primary objective of MIT is to develop a sense of race pace and enhance the body system's ability to sustain exercise at that pace [48].

Although experimental studies have shown LIT and HIT to be more effective at inducing adaptation, descriptive studies on training intensity distribution (TID) seem to suggest that MIT should not be disregarded entirely for WTCs. Most retrospective studies on elite and professional cyclists have reported a pyramidal TID, with extensive LIT (~78%), less MIT (~17-20%), and even less HIT (~2.5-5%) [49, 50]. The professional cyclists in Lucia et al. [49] increased their fat oxidation and muscle recruitment at submaximal intensities and the elite cyclists in Zapico et al. [50] significantly improved their VO_{2max}, W_{peak}, W_{LT}, and cycling economy. These findings suggest that MIT may indeed be valuable in the training program of WTCs.

1.5.3 High-Intensity Training (HIT)

HIT is vigorous exercise above 80% HR_{max} (but often 85-95% HR_{max}). It is usually performed as 2 to 8-minute intervals with active recovery in between the intervals [51]. HIT repeatedly stresses the physiological systems used in cycling competition at a greater level than the level required during competition [43]. HIT recruits both type I and type II fibers, and thus stresses both the aerobic and anaerobic systems. HIT appears to improve a variety of cycling performance predictors such as VO_{2peak}, W_{peak}, W at LT, and performance in 40km time trials [43, 52]. The mechanisms underlying improved performance in trained endurance athletes following HIT seem to be increased VO_{2max} [22, 53, 54], skeletal muscle buffering capacity [55] and increased effectiveness of important enzymes in the production of ATP [56]. Although HIT provides beneficial training adaptations, large volumes of high-intensity exercise can down-regulate the sympathetic nervous system [57], and Esteve-Lanao et al.[58] observed that a total HIT volume higher than 25% was too demanding to be followed by sub-elite endurance runners for more than 2 to 3 weeks. This is possibly why trained cyclists and other endurance athletes traditionally do two HIT sessions per week [43, 59, 60].

1.6 Periodization of Endurance

1.6.1 General

Although most researchers seem to agree that a training plan should incorporate all the training intensities, they are not as certain regarding the best method of organizing training. Periodization is the systematic planning and structuring of training variables in defined timeframes in an attempt to optimize training adaptations and performance and minimize the risk of injury [42, 61]. A periodization program consists of the general conditioning, sport-specific activity and resistance training of an athlete. The success of a periodization plan depends on the management of the adaptive response and accumulated fatigue.

Periodization programs are made up of a hierarchy of training cycles (Table 2). The longest time periods for most athletes are called macrocycles, which usually represent several months to a year. Macrocycles are comprised of smaller training cycles called mesocycles, which last 2-6 weeks, although the most common duration is 4 weeks [48, 62]. Mesocycles are comprised of microcycles, which are commonly 1 week in duration. The smallest cycle in the hierarchy is a training session. Classically, a training year is divided into a preparatory period, which focuses on generalized preliminary work, a competition period, which includes more event-specific work and competitions, and a transition period, which focuses on recovery [42]. The most important phase for developing physiological capacities in WTCs is the preparatory period.

Several research findings have been made concerning general aspects of organizing training for the purpose of improved performance. Regarding the optimal length of a mesocycle, the literature points to a 4-week period as being an optimal biological window for integrating responses [63]. Additionally, research suggests that a 1-week unloading phase at the end of a 4-week cycle can reduce fatigue and provide time for adaptation and supercompensation to take place [64, 65]. Furthermore, variation in training appears to be important for preventing overtraining and stagnation [66]. A lack of variation in training fails to challenge the nervous system to adapt due to the principle of diminishing returns [63]. Thus, periodization in the preparatory period should consider changing volume, intensity, and frequency of training and including novel or semi-novel tasks to increase variability in the training plan [67].

Table 2. Structural hierarchy of periodization programs.

Preparation component and its duration	Content
Multi-year preparation (years)	Long-lasting systematic athlete training composed of 2-year or 4-year (quadrennial) cycles
Macrocycle (months)	Large size training cycle (frequently annual cycle) that includes preparatory, competition and transition periods
Mesocycle (weeks)	Medium size training cycle consisting of a number of microcycles
Microcycle (days)	Small size training cycle consisting of a number of days; frequently 1 week
Workout (h/min)	A single training session that is performed individually or within a group

Taken from Issurin [62]

General findings concerning training intensity distribution (TID) have also been made. The first finding regarding TID is that a majority of highly-trained endurance athletes and road cyclists use a pyramidal TID, in which athletes perform a high volume of LIT, less MIT, and even less HIT in the preparatory period [40]. Although a pyramidal TID is more practiced, research points to a polarized distribution (80% LIT, 20% HIT) as being the most effective for improving VO_{2peak}, W_{peak}, W_{LT}, and high-intensity exercise capacity [54, 68]. Furthermore, research on the organization of HIT within a mesocycle has found that how different intensities of HIT are periodized does not seem to have an effect on VO_{2max}, W_{peak}, and W_{mean} in 40-minute all-out efforts on the bike [29].

1.6.2 Periodization Models of Endurance in the Preparatory Period

1.6.2.1 Traditional Periodization

Traditional periodization (TRAD) is characterized by gradual, wave-like increases in workload [65]. The wave principle is an important part of TRAD theory that states that high training loads should be followed up by medium or low training loads [62]. Hence, HIT is generally dispersed with lower intensity training in TRAD in the programs of endurance

athletes. The rational for sequencing workloads in this way is increased probability of favourable training responses and the prevention of excessive fatigue accumulation. The wave sequencing of training is implemented on a macrocycle, mesocycle, and microcycle level, with the amount of variation dependent on the level of an athlete (higher levels means more variation required) [65]. Medium waves in monthly training and large waves in the annual training plan (e.g. preparatory period) are intended to refresh an athlete's adaptability and avoid the monotony of repetitive training routines. What results is an undulating increase in workload, which is why TRAD is sometimes described as a linear periodization model. Additionally, TRAD is characterized as a model in which many fitness components (e.g. aerobic capacity, maximal aerobic power, maximum strength) are developed simultaneously [69].

The preparatory period in TRAD focuses on more generalized and preliminary work. It consists of a high volume of exercises targeted to develop mostly general physical and technical abilities. Preparatory period training for high-performance endurance athletes usually contains a program for the development of general aerobic ability, muscle strength and strength endurance, improvement of general coordination, general explosive ability and general speed, as well as basic mental and technical preparation [62].

1.6.2.2 Block Periodization

Block periodization (BLOCK) is a training cycle of highly concentrated specialized workloads [70]. A block in BLOCK contains a large volume of exercises directed at a minimal number of targeted abilities, and non-selected target abilities are left with little to no stimulation. Development in BLOCK is consecutive, meaning that two consecutive blocks will be focusing on different target abilities [62]. For endurance programs, BLOCK is structured so that a block directed towards developing aerobic capacity is performed first. This block is followed by a sport-specific block which focuses on aerobic-anaerobic or glycolytic endurance, and a block focusing on recovery before a competition [71]. Successful BLOCK relies on maintaining a residual training effect, which is the retention of changes induced by systematic training beyond a certain time period after the cessation of training [70].

1.6.2.3 Comparison Studies on Block Versus Traditional Periodization

Research comparing BLOCK versus TRAD seems to point to BLOCK inducing greater adaptations and performance improvements in endurance athletes [71]. Intervention studies comparing BLOCK versus TRAD in endurance sports have studied kayakers, skiers, and cyclists of a trained to professional level for a period of 11 days to 3 years. Factors that showed significant improvements in these studies include VO_{2max}, LT_w, W_{peak}, and improved results in performance tests [71]. The volume of HIT between groups was unfortunately not controlled for in several of the studies, making it difficult to identify whether the observed differences were due to block periodization or the increased volume of HIT in the block groups.

BLOCK research on cyclists has almost exclusively investigated the effects of HIT blocks. Ronnestad, Hansen, and Ellefsen [59] compared the effects of 1 week of HIT block training followed by 3 weeks of LIT training versus traditional training in 21 well-trained cyclists for 4 weeks. Despite only 4 weeks of training, the BLOCK group significantly improved their VO_{2max}, W_{peak}, and power output at 2 mmol·L^{-1}, while no changes occurred in the TRAD group. Ronnestad et al. [72] performed a follow-up study using the same protocol for 12 weeks. BLOCK once again induced greater improvements than TRAD in relative VO_{2max}, W_{peak}, and body mass-adjusted mean power output during a 40-min all-out trial and tended to show larger relative improvements in power output at 2 mmol·L^{-1} and gross efficiency. Additionally, intense blocks of HIT in the form of running has also been found to improve cycling VO_{2max} and time trial performance [73].

According to the author's knowledge, only two studies in endurance sports have investigated the systematic block periodization of LIT, MIT, and HIT. Garcia-Pallares et al. [69] performed a cross-over study with 10 world-class kayakers over two consecutive seasons, in which the kayakers followed a TRAD training program during the first season and switched to a BLOCK program for the second. The researchers found that both the TRAD and BLOCK cycles resulted in similar improvements in VO_{2peak} and VO_2VT2, even though the TRAD cycle was 10 weeks and 120 training hours longer than the BLOCK cycle. However, the BLOCK groups experienced larger improvements in peak paddling speed at VO_{2peak}, W_{peak}, and stroke rate at VO_{2peak} than those observed with TRAD. Nevertheless, it is important to note that the kayakers performed 10% more training above VT2 during the BLOCK cycle,

which means that the improvements seen in the BLOCK cycle may have been due to the greater volumes of HIT. Another drawback of this study is that it does not report on how the training intensities in the BLOCK cycle were organized. The only study that has done so is a case study by Ronnestad and Hansen [74].

Ronnestad and Hansen [74] investigated the effects of 58 weeks of systematic BLOCK (block periodization of LIT, MIT, and HIT) on physiological and performance variables in a cyclist that can be considered professional. The cyclist showed significant improvements in VO_{2max}, relative W_{peak}, and power output at 3 mmol•L^{-1} after the intervention, and the magnitude of his improvements was higher than what is normally seen in the professional level. This suggests that systematic BLOCK of all three training intensities can be an effective training program strategy. However, given that only one subject underwent the intervention, the results from this case study have little power. Therefore, there is a need for a systematic BP intervention study that includes more subjects in order to have a more accurate picture of the effectiveness of systematic BLOCK as a periodization strategy.

1.7 Aims and Hypotheses

The primary aim of this thesis is to compare the effects of systematic BLOCK with TRAD organization of endurance training on performance and physiological indicators over a period of 12 weeks of the preparatory period.

It is hypothesized that 12 weeks of systematic BLOCK will induce significantly greater improvements than TRAD on VO_{2max}, W_{peak}, W_{4mmol}, and mean power output in a 40-minute time trial than TRAD among well-trained cyclists.

2. Methods

2.1 Subjects

25 healthy, trained/well-trained cyclists participated in the project. The cyclists had been cycling competitively for a minimum of 2 years. The average age of the subjects was 37.2 ± 11.0 years. The subjects were required to attend a minimum of 80% of the supervised trainings in order for their data to be used for the results. The total number of subjects was

initially 29, however, one subject had to withdraw due to injury, another due to work commitments, another for unstated reasons, and one for not completing at least 80% of the trainings (Figure 1). All the subjects that participated signed a written consent form and the protocol throughout the study was conducted in accordance with the Helsinki Declaration and approved by the NSD.
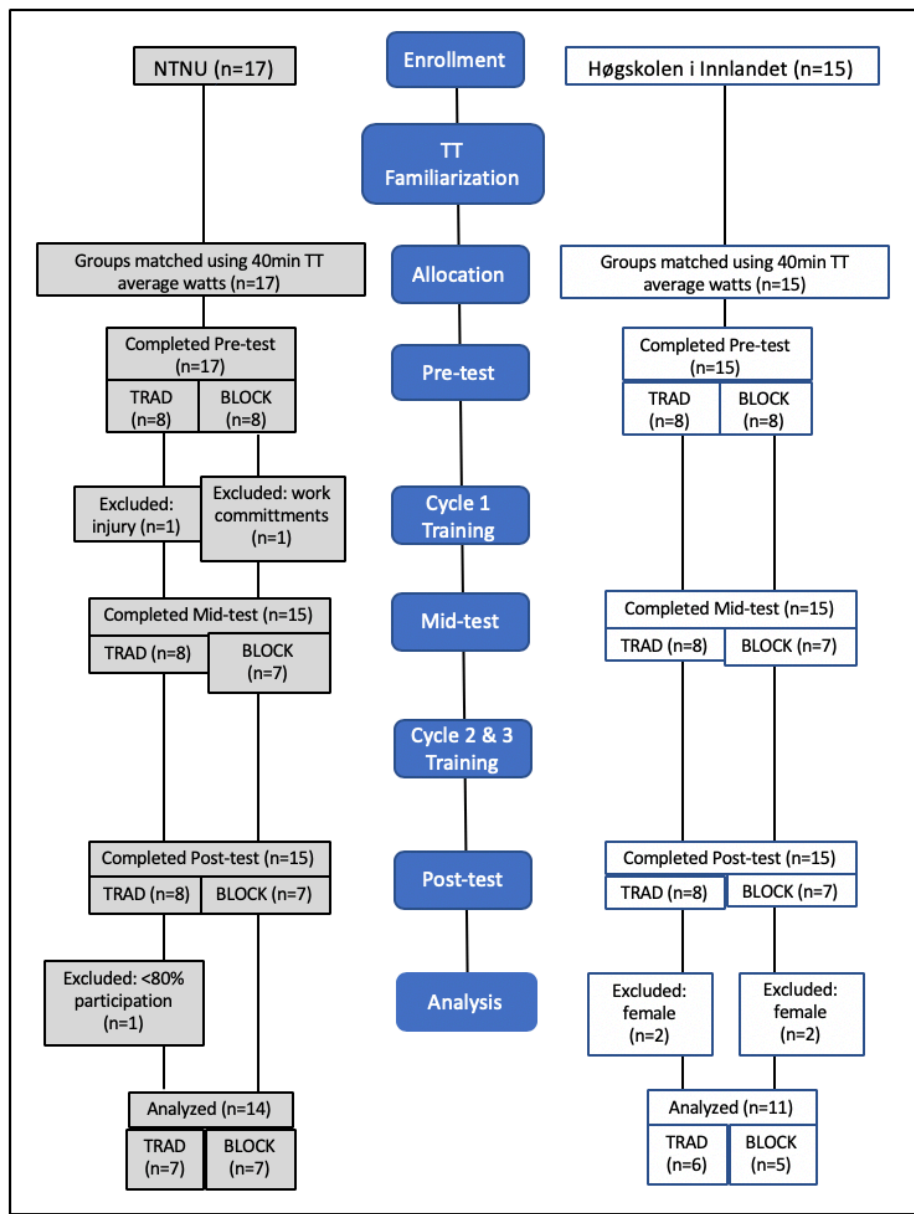

Figure 1. Study flow chart.

2.2 Test Procedures and Materials

2.2.1 Test Day One

The baseline measurements for all the participants began with a 10-minute warm up below 200 W on an electromagnetically-braked cycle ergometer (Lode Excalibur Sport, Lode B. V., Groningen, the Netherlands). Seat height, horizontal distance between tip of seat and bottom bracket, and handlebar position were changed according the cyclist's preferences and used for pre- and post-testing. Cyclists were allowed to choose their preferred cadence during all cycling and used their own shoes and pedals. After the warm up, the subjects sat in a Keiser Leg Press Machine (Keiser Co. Inc., Fresno, California, U.S.A.) to have their maximum strength (1 RM) measured. The subjects performed each repetition as quickly and forcefully as possible until they could no longer perform a full leg extension. Knee angle at starting position was adjusted to be 90 degrees.

The strength test was followed by a lactate profile test to find each subject's lactate threshold. The test began at 100 W and power was increased by 50 W every 5 minutes until a blood lactate measurement of around 3.0 $mmol \cdot L^{-1}$ blood lactate was reached. Once around 3.0 $mmol \cdot L^{-1}$ blood lactate was reached, the power was only increased by 25 W per 5 minutes until a blood lactate measurement of 4.0 $mmol \cdot L^{-1}$ blood lactate or above was reached. VO_2, RER, and HR were measured in the 2 to 4-minute period of each segment. Subjects were asked for their rating of perceived exertion (RPE) using a Borg scale (6-20) in the final minute of each segment and blood was collected via fingertip in the final 30 seconds for blood lactate analysis. After 4.0 $mmol \cdot L^{-1}$ blood lactate was reached, the subjects cycled at a low intensity for five minutes. Cycling efficiency was calculated for each segment of the test.

The lactate profile test was followed by a 6-second all-out sprint to measure maximum power output. The subjects started their sprint in a static position and remained seated for the entire sprint. After the sprint, the subjects cycled another 5 minutes at low intensity before doing a VO_{2max} test. The purpose of the VO_{2max} test was to acquire each subject's maximum oxygen uptake and W_{peak}. The subjects began the test at either 100 or 200 W depending on whether the tester believed the subject would have a W_{peak} below or above 400 W. Power output was increased by 25 W every minute until the subjects could no longer continue cycling. Subjects were given encouragement in the later stages to aid them in reaching their VO_{2max}. VO_2, RER, and HR were measured throughout the test. Subjects were asked for their RPE rating

immediately following the end of the test, and a blood lactate sample was taken 1 minute after the end of the test. A 10-minute break followed the VO_{2max} test, in which the subjects were given an opportunity to eat something or drink an energy drink.
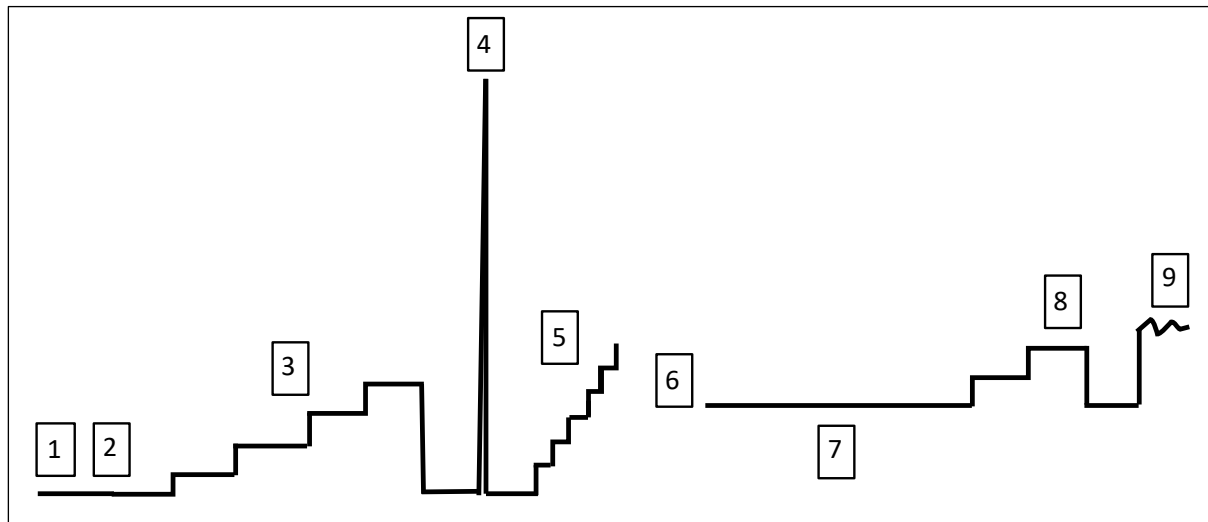

Figure 2. Graphical representation of testing protocol. 1 = 10-minute warm up, 2 = 1RM strength test, 3 = lactate profile, 4 = 6-second sprint, 5 = VO_{2max} test, 6 = 10-minute break, 7 = 30 minutes at 60% VO_{2max} power, 8 = 5-minute segments at 3rd and 2nd last lactate profile power output and 60% VO_{2max} power, 9 = 5-minutes all out.

The second half of Day 1 testing began with 30 minutes of cycling at 60% VO_{2max} power. RPE, HR, and RPM were recorded, and blood lactate measured every 5-minutes throughout the 30 minutes and during the 29th minute. This was immediately followed by three 5-minute segments at a power output equal to the third and second last segment of the lactate profile test, and 60% VO_{2max} power. HR, RPE, RPM were recorded, and blood lactate measured at the end of each segment. The purpose of this was to measure cycling efficiency during a fatigued state. The same procedure was adhered to for the 5-minute segments as during the lactate profile test. The final test was a 5-minute all-out time trial which was performed after 5 minutes of cycling at 100W. W, HR, and RPM were recorded for each minute of the 5-minute all-out trial.

Blood lactate was measured using a stationary lactate analyzer (EKF BIOSEN; EKF Diagnostics, Cardiff, UK). VO_2, VE, and RER were measured using Oxycon Pro (Oxycon; Jaeger GmbH, Hoechberg, Germany). HR was measured with the subject's own heart rate

monitor. LT_W was calculated using linear interpolation as the power output at 4 mmol·L^{-1} blood lactate. A test result was considered VO_{peak} if: a plateau in the VO_2 curve was seen; HR was ≥ 95% of known HR_{max}, RER was ≥ 1.10; and blood lactate was ≥ 8 mmol·L^{-1}. W_{peak} was calculated as the mean power output during the last minute of the VO_{2max} test and HR_{peak} was recorded as the mean HR during the last 5 seconds. The subjects maintained a cadence that was comfortable for them throughout the procedure. If subjects' cadence was over ± 10 from their chosen cadence, they were asked to return back to that zone. Cycling efficiency was calculated using $\left(\frac{Mechanical\ Power\ Output}{Metabolic\ Internal\ Power}\right) \cdot 100$ according to Noordhof, Skiba, and de Koning. [75].

2.2.2 Test Day Two

The second day of testing comprised of a 40-minute all-out time trial. The time trials were performed on the cyclist's own road bikes. The bikes were mounted on Computrainer Lab^{TM} ergometers (Race Mate, Seattle, WA) and calibrated according to the manufacturer's specifications and connected to a central PC running dedicated software (PerfPRO Studio, Hartware Technologies, Rockford, MI). Mean power output (W_{40TT}), speed in km/h, and cadence were recorded. All cyclists performed a 40-minute all-out time trial with the same set up prior to pre-testing to become familiar with the test.

Pre- and post-testing occurred at the same time of the day when possible. The cyclists were instructed to do no intense exercise on the 2 days preceding testing and to eat the same type of meal before each test. They were not allowed to eat during the 2 hours before the tests and were instructed to refrain from ingesting alcohol during the 24 hours before the tests and from caffeine during the 8 hours prior to the tests. All tests were performed under similar environmental conditions (20–22 °C).

2.3 Training Intervention

Following pre-testing, the subjects were placed into a block periodization (BLOCK) or traditional periodization (TRAD) group. The subjects were rank-ordered based on their relative W_{mean} during the 40-minute time trial and randomized into either the BLOCK or

TRAD group. The training intervention consisted of 12 weeks of LIT, MIT, and HIT workouts. Both groups performed an equal amount of MIT and HIT and did an amount of LIT that they were accustomed to prior to the study. MIT and HIT session compliance were $98.7 \pm 4.6\%$ and $96.2 \pm 5.5\%$ for the TRAD group and $97.9 \pm 5.2\%$ for the BLOCK group. The total amount of LIT, MIT, and HIT was the same for both groups ($P > 0.05$, Table 3).

LIT sessions were done at a low intensity and participants were allowed to perform the LIT sessions as endurance exercise other than cycling. MIT sessions were 12-minute intervals and HIT sessions 5-minute intervals, both with 3-minute recovery period between intervals. Intensity guidelines for the MIT and HIT workouts were based according to RPE. The subjects were instructed to begin their MIT and HIT workouts at an intensity around 16 on the Borg scale and to increase the intensity for their subsequent intervals. The final interval for both MIT and HIT workouts were instructed to be an all-out effort. Warm ups and cool downs were performed at low intensity and their durations were self-selected among the athletes.

Table 3. Mean hours of low-intensity, moderate-intensity, and high-intensity training during the training intervention.

	TRAD				BLOCK			
Week	1 - 4	5 - 8	9-12	Total	1 - 4	5 - 8	9 -12	Total
LIT	111.4 ± 82.9	113.6 ± 106.6	76.2 ± 79.5	301.2 ± 89.6	66.9 ± 86.4	67.0 ± 84.5	68.7 ± 86.4	202.6 ± 85.8
MIT	3.2 ± 0.0	3.2 ± 0.0	3.1 ± 0.4	9.4 ± 0.4	3.1 ± 0.2	3.1 ± 0.2	3.1 ± 0.2	9.4 ± 0.5
HIT	1.6 ± 0.2	$1.7 \pm 0.0^*$	$1.6 \pm 0.2^{**}$	4.8 ± 0.3	1.6 ± 0.2	$1.7 \pm 0.0^*$	$1.6 \pm 0.1^{**}$	4.9 ± 0.2

Values are mean ± standard deviation.
[#]Difference between TRAD and BLOCK.
[*]Difference between weeks 1 – 4 and 5 – 8 ($P < 0.05$).
[**]Difference between weeks 5 – 8 and 9 – 12 ($P < 0.05$).
LIT, low-intensity training; MIT, moderate-intensity training; HIT, high-intensity training.

Training was organized for both groups into three cycles of 4 weeks. The BLOCK cycle consisted of 4 MIT sessions during week 1, LIT workouts during week 2, 4 HIT sessions during week 3, and a recovery week during week 4. The BLOCK group performed 4 x 12-minute intervals for their MIT week and 5 x 5-minute intervals for their HIT week. The TRAD cycle consisted of 1 MIT and HIT workout per week and LIT. The number of intervals in the MIT and HIT sessions increased throughout the first three weeks of the cycle from 3 x 12 to 5 x 12 minutes for the MIT sessions and from 4 x 5 to 6 x 5 minutes for the HIT sessions. An additional 4 x 12-minute session was performed during week 3 of every cycle

and a 5 x 5-minute workout during the beginning of week 4. The remainder of week 4 for each cycle was dedicated to recovery. Subjects in both groups were asked to maintain their volume of LIT performed during the first cycle in the subsequent cycles. Subjects were instructed to do a low volume of low intensity endurance exercise during week 4 of each cycle.
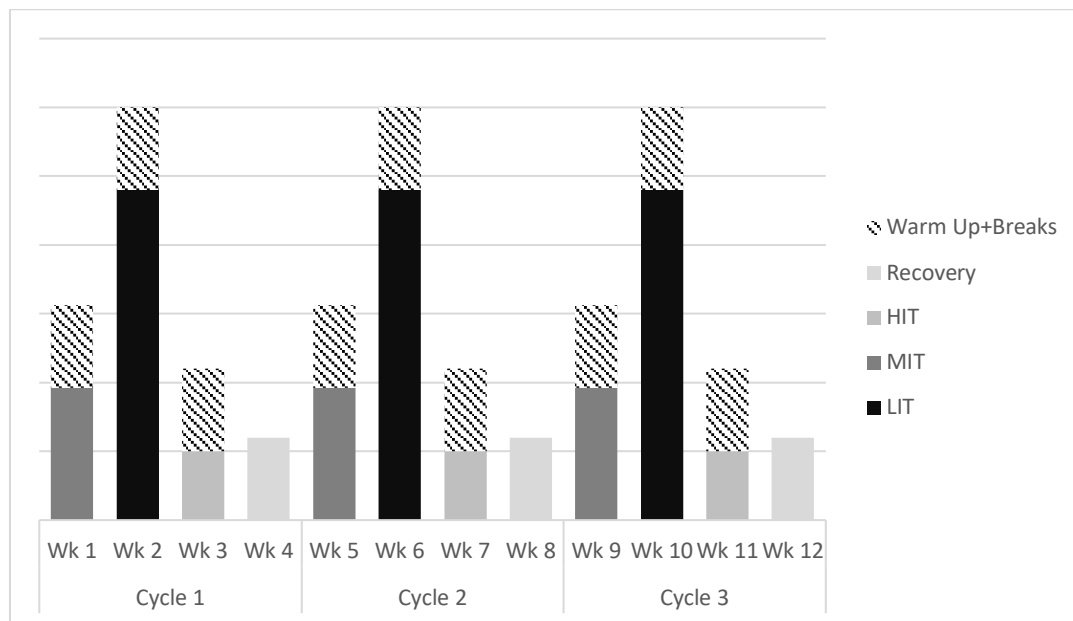

Figure 3. BLOCK group training organization.

HIT, high-intensity interval training; MIT, moderate-intensity interval training; LIT, low-intensity interval training.

Recording of certain information was required throughout the training intervention. Subjects were advised to wear a pulse belt and measure their HR for all workouts, especially the MIT and HIT sessions per 4-week cycle. All subjects were required to attend a minimum of 2 MIT and HIT supervised sessions. Subjects performed these sessions with their own bikes on Computrainer Lab™ ergometers (Race Mate, Seattle, WA). Mean power output, mean HR, and RPE were recorded per interval. Blood lactate samples were collected per interval as well for 2 or 3 subjects each supervised session. Mean power output data was collected using PerfPRO Studio software (PerfPRO Studio, Hartware Technologies, Rockford, MI). HR, RPE, and blood lactate data was collected using the same procedures and materials as during lab testing. Session RPE (sRPE) was recorded after every workout. All training performed during the training intervention was added to TrainingPeaks.
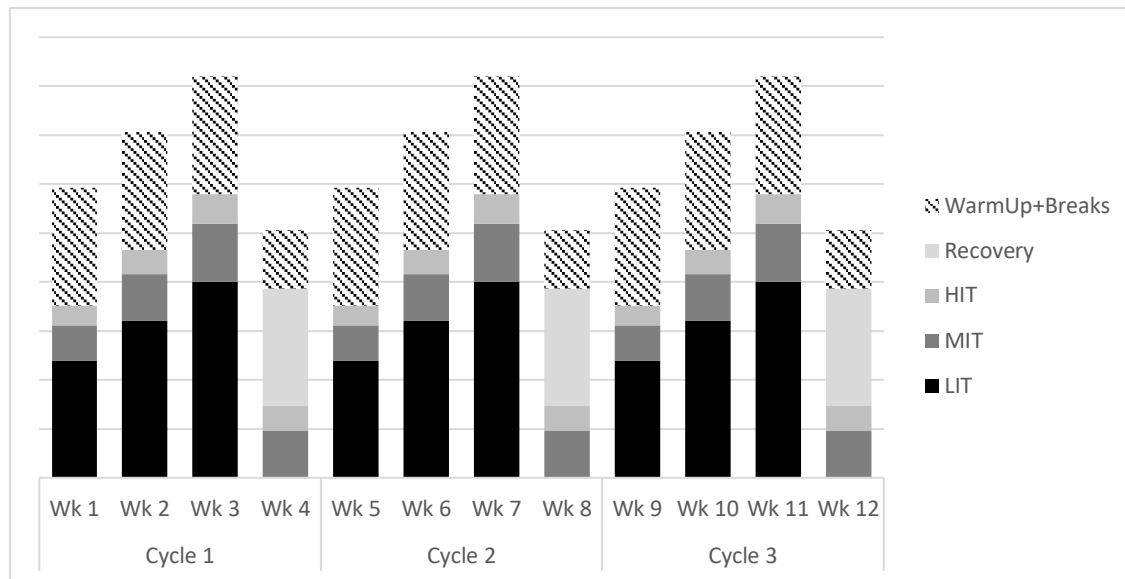
Figure 4. TRAD group training organization.

HIT, high-intensity interval training; MIT, moderate-intensity interval training; LIT, low-intensity interval training.

2.4 Statistical Analyses

Normality of the pre-test group data was calculated using the Shapiro-Wilkes test. Significant between-group differences were calculated using an using two-tailed two samples Students t-tests, and within-group differences during the pre-, mid-, and post-test were calculated using a two-way repeated measures ANOVA. A Tukey's honestly significant difference (HSD) test was performed for post-hoc analysis if the ANOVA reached significance. Differences in total LIT, MIT, and HIT training volume between groups were tested for significance using a two-tailed two samples Students t-test. Effect size was calculated as Cohen's d to compare the practical significance of the performance improvements among the two groups. The criteria to interpret the magnitude of the effect size were the following: 0.0 – 0.2 trivial, 0.2 – 0.6 small, 0.6 – 1.2 moderate, 1.2 – 2.0 large, and > 2.0 very large [76]. Calculations of the independent variables were performed on Excel 2016 (Microsoft Corporation, Redmond, Washington, USA) and The Statistical Package for the Social Sciences (Version 23.0.0.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. All analyses resulting in P ≤ 0.05 were considered statistically significant.

3. Results

3.1 Physiological Variables

No significant between-group differences were seen for relative W at 4mmol/L blood lactate (W_{4mmol}), $\%HR_{max}$ at 4 mmol/L blood lactate, $\%VO_{2max}$ at 4 mmol/L blood lactate, relative VO_{2max}, or body mass (Table 4). Additionally, there was no significant difference in efficiency between the groups (Figure 5). However, significant differences in absolute W_{4mmol} and VO_{2max} were found between the groups. The TRAD group had a significantly higher absolute W_{4mmol} (P = 0.03) at the post-test compared to the BLOCK group. The mean absolute W_{4mmol} was 29.9 ± 4.4 W (11.1 ± 1.6%) higher in TRAD compared to BLOCK. The TRAD group also had a significantly higher absolute VO_{2max} (P = 0.01) compared to the BLOCK group during the pre-, mid-, and post-tests (P = 0.02, P = 0.02, P = 0.04). The mean absolute VO_{2max} was 0.53 ± 0.07 L (11.7 ± 1.5%) higher in TRAD compared to BLOCK during the pre-test, 0.52 ± 0.03 L (11.3 ± 0.7%) higher during the mid-test, and 0.54 ± 0.01 L (11.6 ± 0.2%) higher during the post-test. Mean effect sizes were trivial (ES < 0.2) for the relative differences in VO_{2max} and W_{4mmol} of TRAD vs BLOCK periodization. However, a moderate effect size (ES = 0.71) favoring BLOCK periodization versus TRAD periodization was found for efficiency.

Significant differences across time were exhibited for both TRAD and BLOCK (Table 4). Absolute and relative W_{4mmol} (P = 0.00) and relative VO_{2max} (P = 0.03) were the only variables that significantly increased from the pre- to post-test. Absolute W_{4mmol} increased by 21.3 ± 32.6 W (7.6 ± 11.7%) for TRAD and by 19.7 ± 24.7 W (7.9 ± 9.9%) for BLOCK. Relative W_{4mmol} increased by 0.3 ± 0.4 (8.6 ± 11.6%) in TRAD and by 0.3 ± 0.1 (7.4 ± 10.4%) in BLOCK. Relative VO_{2max} increased by 1.7 ± 3.7 ml·kg^{-1}·min^{-1} (2.9 ± 6.1%) for TRAD and by 1.6 ± 3.7 ml·kg^{-1}·min^{-1} (2.8 ± 6.4%) for BLOCK.

Other significant differences across time were also found (Table 4). Significant changes occurred between pre-testing and mid-testing for $\%HR_{max}$ at 4 mmol/L blood lactate (P = 0.01) for both groups. $\%HR_{max}$ at 4 mmol/L blood lactate decreased by 2.5 ± 4.0% from pre- to mid-test for TRAD and by 1.6 ± 3.6% for BLOCK. Significant mid-test to post-test changes occurred for absolute and relative W_{4mmol} (P = 0.00), $\%VO_{2max}$ (P = 0.02) at 4 mmol/L blood lactate and efficiency (P = 0.04) for both groups. Absolute W_{4mmol} increased by 21.8 ± 21.8 W (7.9 ± 10.0%) for TRAD and by 11.4 ± 22.8 W (4.4 ± 8.8%) for BLOCK,

while relative W_{4mmol} increased by 0.3 ± 0.3 ($8.3 \pm 7.6\%$) for TRAD and by 0.13 ± 0.26 ($3.9 \pm 7.9\%$) for BLOCK. $\%VO_{2max}$ at 4 mmol/L blood lactate increased by $4.8 \pm 6.6\%$ for TRAD and $1.1 \pm 5.1\%$ for BLOCK. Lastly, efficiency increased by $0.2 \pm 1.1\%$ for TRAD and $0.6 \pm 0.9\%$ for BLOCK.

Table 4. Data from the physiological tests before (pre), four weeks in (mid) and after (post) the training intervention in the traditional (TRAD) and block (BLOCK) training group.

	TRAD (N = 13)			BLOCK (N = 12)		
	Pre	Mid	Post	Pre	Mid	Post
4 mmol·L^{-1} (W)	278.1±40.9	277.5±33.8	299.3±34.5[#*‡]	249.7±34.1	258.0±31.5	269.4±30.1[*‡]
(W·kg^{-1})	3.3±0.5	3.3±0.5	3.9±0.4[*‡]	3.2±0.6	3.3±0.5	3.4±0.4[*‡]
(%HR$_{max}$)	87.0±5.0	84.6±4.4[†]	86.7±3.9	87.7±4.3	86.1±5.1[†]	85.6±4.8
(%VO$_{2max}$)	77.2±7.3	76.0±6.5	80.8±6.2[‡]	77.9±6.3	78.5±4.2	79.6±5.4[‡]
VO$_{2max}$ (L)	5.05±0.5[#]	5.10±0.49[#]	5.17±0.52[#]	4.52±0.57	4.58±0.52	4.63±0.53
(ml·kg^{-1}·min^{-1})	60.2±8.0	60.8±7.2	61.9±6.8[*]	56.8±7.2	57.9±7.1	58.3±6.7[*]
BM (kg)	84.7±9.7	84.5±9.2	83.9±8.5	79.9±8.2	79.5±7.9	79.8±8.1

Values are mean ± standard deviation.
[#]Difference between TRAD and BLOCK ($P < 0.05$).
[*]Difference between pre and post ($P < 0.05$).
[†]Difference between pre and mid ($P < 0.05$).
[‡] Difference between mid and post ($P < 0.05$).
4 mmol·L^{-1}, at blood lactate concentration of 4 mmol/L; W, watts; %HRmax, percentage of maximum heart rate; VO_{2max}, maximum oxygen uptake; L, litres of oxygen; BM, body mass; Δ, mean pre to post change.
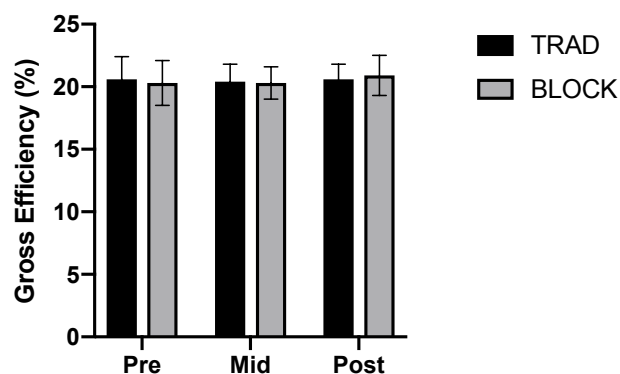

Figure 5. Cycling efficiency of the second last stage of the lactate profile before (Pre), 4 weeks in (Mid), and after (Post) the training intervention.

3.2 Performance Indicators

No significant differences were found in relative peak power output (W_{peak}) and W/kg in the 40-minute time-trial (W_{40TT}) between the groups. Significant differences in absolute W_{peak} and W_{40TT} were found between the groups (Figure 6 and 7). Absolute W_{peak} and W_{4mmol} were found to be significantly higher in TRAD compared to BLOCK. Absolute W_{peak} was significantly higher in TRAD compared to BLOCK during the pre-, mid-, and post-tests (P = 0.02, P = 0.00, P = 0.04). Absolute W_{peak} in TRAD was 37.0 ± 1.9 W (9.3 ± 0.5%) higher than BLOCK during the pre-test, 37.9 ± 2.3 W (9.3 ± 0.6%) higher during the mid-test, and 32.5 ± 8.6 W (7.6 ± 2.0%) higher during the post-test. Absolute W_{40TT} was significantly higher in TRAD compared to BLOCK during the post-test (P = 0.04). Absolute W_{40TT} was 25.8 ± 7.4 W (8.9 ± 2.6%) higher in TRAD compared to BLOCK during the post-test. Mean effect sizes of TRAD versus BLOCK periodization were trivial (ES < 0.2) for W_{peak} and W_{40TT}.

Significant improvements across time were seen for all performance variables in both groups (Figure 6 and 7). Improvements were seen from the pre-test to the post-test for all performance variables (P = 0.00). Absolute and relative W_{peak} improved by 28.8 ± 13.8 W (6.7 ± 3.2%) and 0.4 ± 0.2 W/kg (7.5 ± 3.0%) for the TRAD group, and by 33.3 ± 22.2 W (8.5 ± 5.6%) and 0.4 ± 0.3 W/kg (8.4 ± 6.9%) for the BLOCK group. Absolute and relative W_{40TT} improved by 18.5 ± 25.4 W (6.2 ± 8.6%) and 0.2 ± 0.3 W/kg (7.0 ± 7.7%) for the TRAD group, and by 14.4 ± 17.3 W (5.2 ± 6.3%) and 0.2 ± 0.2 W/kg (5.8 ± 6.4%) for the BLOCK group.

Significant improvements in relation to the mid-test were also found for W_{peak} (Figure 6). Absolute and relative W_{peak} increased significantly from the pre-test to the mid-test (P = 0.00). Absolute and relative W_{peak} improved by 15.4 ± 12.7 W (3.6 ± 2.9%) and 0.2 ± 0.1 W/kg (4.1 ± 2.7%) respectively from pre- to mid-test for TRAD, and by 14.6 ± 19.8 W (3.7 ± 5.0%) and 0.2 ± 0.3 W/kg (3.9 ± 5.0%) respectively for BLOCK. Absolute and relative W_{peak} also increased significantly from the mid-test to the post-test (P = 0.00). Absolute and relative W_{peak} improved by 13.5 ± 13.0 W (3.0 ± 2.9%) and 0.2 ± 0.1 W/kg (3.3 ± 2.9%) respectively for TRAD, and by 18.8 ± 24.1 W (4.6 ± 5.9%) and 0.2 ± 0.3 W/kg (4.4 ± 6.2%) respectively for BLOCK.
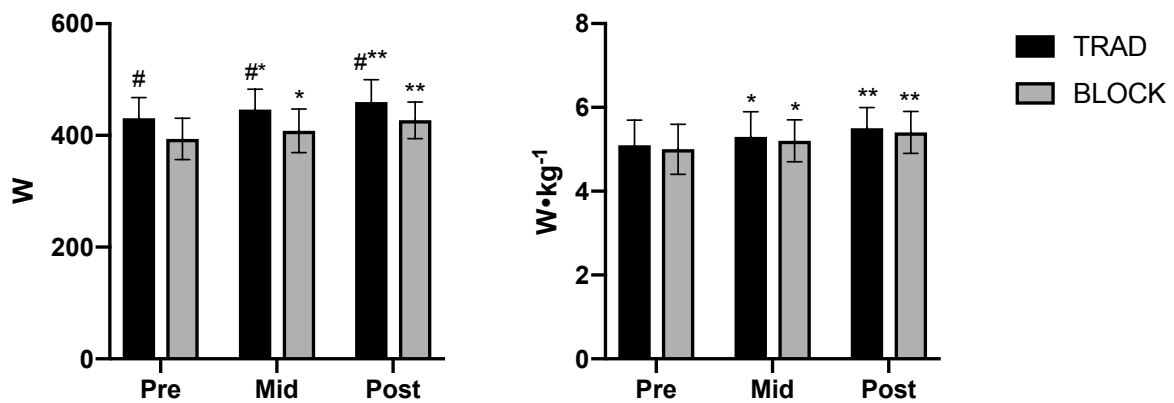
Figure 6. Absolute (left) and relative (right) power output at VO_{2max}. [#]Difference between TRAD and BLOCK ($P < 0.05$). [*]Difference between Pre and Mid ($P < 0.05$). [**]Difference between Mid and Post ($P < 0.05$).
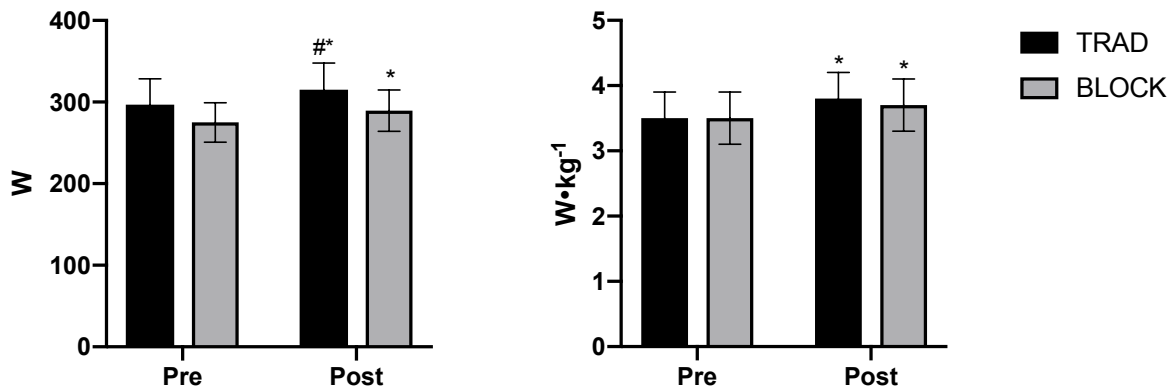
Figure 7. Mean absolute and relative power output during the 40-minute time trial. [#]Difference between TRAD and BLOCK ($P < 0.05$). [*]Difference between Pre and Post ($P < 0.05$).

4. Discussion

The main finding of this study is that systematic block periodization and traditional periodization of endurance training showed similar improvements in physiological and performance variables for well-trained cyclists during the preparatory period. Both periodization models led to similar improvements in W_{4mmol}, VO_{2max}, W_{peak}, and W_{40TT}. The TRAD group exhibited significantly higher absolute values for all these variables compared to BLOCK, but these differences were not significant when adjusted for body mass. Cycling efficiency did not significantly improve after 12 weeks of training for both the TRAD and BLOCK group. Effect size results indicate that the magnitude of the improvements in W_{4mmol}, VO_{2max}, W_{peak}, and W_{40TT} was the same for traditional and systematic block periodization, but

that the magnitude of the improvement in efficiency was moderately greater for systematic block periodization. A secondary finding was that traditional and systematic block periodization led to similar improvements across time in VO_{2max}, W_{peak}, and W_{40TT}, but not in W_{4mmol}, where traditional periodization showed slower improvement compared to systematic block periodization.

4.1 <u>Physiological Variables</u>

4.1.1 VO_{2max}

Both traditional and systematic block periodization led to improvements in VO_{2max} over 12 weeks of training in the present study. The TRAD group improved their VO_{2max} by $2.9 \pm 6.1\%$ while the BLOCK group improved by $2.8 \pm 6.4\%$. The improvements in VO_{2max} are most likely due to the HIT performed by each group, as HIT has been attributed to improvements of VO_{2max} in well-trained endurance athletes [43]. The effect size of $d = 0.1$ indicates that the magnitude of the improvement in VO_{2max} was the same for periodization models, suggesting that traditional and systematic block periodization are equally effective at improving VO_{2max}.

The percentages of improvement seen in the present study are slightly lower than what has been reported in the literature, with improvements ranging from around 5% for TRAD and around 5-10% for BLOCK [69, 74]. A possible reason for this discrepancy is that the volume of MIT and HIT performed in the present study was considerably lower than what has been reported in similar studies. The cyclist in Ronnestad et al. [74] performed 3 times more MIT and 2 times more HIT than in the present study. Similarly, kayakers in Garcia-Pallares et al. [69] performed 6.5 times more MIT and 2 time more HIT during the first 12 weeks of their TRAD season, and 3.6 time more MIT and 5x more HIT during the first 12 weeks of their BLOCK season. Interestingly, subjects in the present study performed much more LIT than in the Garcia-Pallares et al. [69] study, which suggests that higher volumes of MIT and HIT may be most important for improving VO_{2max} than higher volumes of LIT in the well-trained. A possible explanation for this is that improvements in VO_{2max} have been linked to increased stroke volume [5, 6, 8]. Stroke volume in turn is improved by increased left ventricular contractile force and an increased end-diastolic volume, which requires oxygen delivery to take place at or close to maximal levels.

It is also of note to mention that studies that have only block periodized HIT have reported higher improvements than the present study as well. The BLOCK group in Ronnestad et al. [72] improved their VO_{2max} by 9.7 ± 4.8% while the cyclist in Storen et al. [73] improved by 5.6% after 12 weeks. These findings give support to a polarized training intensity distribution, in which the volume of MIT is reduced to include more LIT and HIT. They also suggest that HIT is the most important intensity to perform to improve VO_{2max}.

Regarding improvements across time, improvements in VO_{2max} for both periodization models only occurred after 12 weeks of training. This finding of the present study differs to the previous the literature, which have reported improvements in VO_{2max} after around 4 weeks of training using block periodization. Ronnestad et al. [59] reported a 4.6% increase in VO_{2max} after 4 weeks of training, and it is estimated that the cyclist would have improved by around 3% after 4 weeks in Storen et al. [73]. Additionally, Bakken [77] reported a 2.6 ± 3.6% improvement in the BLOCK group after 5 weeks of training in cross country skiers and biathletes. A common similarity between these studies are that they did not put emphasis on MIT and block periodized HIT. Nevertheless, the improvements in VO_{2max} for these studies are the same or superior to those in the present study, suggesting that the MIT block in the present study may have been the reason for the lower improvements in VO_{2max} found, and that substituting the MIT block for another HIT block may have led to greater improvements in VO_{2max}.

4.1.2 Cycling Efficiency

Cycling efficiency in the present study did not change for any of the periodization models. This finding was expected as most studies on cycling efficiency seem to suggest that cycling efficiency is not trainable [19]. It is important to note, however, that efficiency studies may have resulted in type II errors due to methodological errors such as 3-minute stages when measuring efficiency (not in steady-state) and using predetermined cycling cadences, and that these studies have had small sample sizes [19]. It is also possible the present study found no change in cycling efficiency due to cadence and diet not being controlled during pre-, mid-, and post-testing for all the subjects, as differences in cadence and diet can influence efficiency [45]. Another possibility is that 12 weeks of training is not long enough to elicit an improvement in efficiency as cycling efficiency has been attributed to years of high-volume

training [19, 45]. Previous research investigating block periodization has also reported no changes in cycling efficiency [72, 73]. These findings suggest that no transition from type IIB muscle fibers to type IIA and ultimately type IIA to type I occurs after 12 weeks of training, which has been attributed to improved cycling efficiency [82, 83]. Although no significant changes in efficiency were found in the present study, a moderate effect on cycling efficiency for BLOCK versus TRAD was found. Subjects in the BLOCK group improved their cycling efficiency on average 0.6% more than subjects in TRAD (d = 0.71), indicating that systematic block periodization may be more effective than traditional periodization for improving cycling efficiency.

4.1.3 Power at Lactate Threshold

Both groups improved their W_{4mmol} and no significant difference was found between the groups. The TRAD group improved their power at 4 mmol/L blood lactate by 8.6 ± 11.6% after 12 weeks of training, and the block group improved by 7.4 ± 10.4%. The magnitude of the improvements in W_{4mmol} seen in TRAD versus BLOCK was the same (d = 0.16), indicating that both periodization models were equally effective at improving power at lactate threshold. A low-moderate relationship (r = 0.39, P = 0.00) was found between the change in W_{4mmol} and the change in VO_{2max}, suggesting that the improvements in VO_{2max} accounts for part of the improvement in W_{4mmol}. This makes sense given that the lactate threshold expressed as $\%VO_{2max}$ does not seem to change [22, 26], meaning that an increase in VO_{2max} should cause an increase in power at the lactate threshold. A low-moderate relationship was also found between cycling efficiency (r = 0.47, P = 0.00), suggesting W_{4mmol} may have shown further improvements had cycling efficiency improved significantly as well. Both LIT [78] and HIT [22, 79] appear to have the ability to improve the lactate threshold in the span of 12 weeks, so it is likely that both training intensities played a role in the power at lactate threshold improvements seen in the present study.

The magnitude of these improvements for TRAD in the present study are in line with previous literature, while the improvements for BLOCK are less. The TRAD group in Ronnestad et al. [72] improved by around 10% while the BLOCK group improved by around 21%. Furthermore, it is estimated that the cyclist in Ronnestad et al. [74] would have improved his power at 3 mmol/L blood lactate by 19.4%. A possible explanation for these

differences is that improvements in power may be greater at lower blood lactate levels, as Ronnestad et al. [72] study measured power at 2 mmol/L blood lactate and Ronnestad et al. [74] at 3 mmol/L blood lactate. Another possible reason is that the number of subjects in the aforementioned studies were too small to show true mean effects. The kayaker study by Garcia-Pallares et al. [69] however, reported a W at VT2 improvement of 5.3% during the TRAD season and 5.8% during the BLOCK season, which is lower than the present study. A noticeable difference between Garcia-Pallares et al. [69] and the present study is that subjects in the present study performed a lot more LIT. Thus, the higher volume of LIT could be the reason for greater improvements in the present study compared to Garcia-Pallares et al. [69]. This explanation is supported by the Ronnestad and Hansen [74] case study, in which the cyclist also performed high volumes of LIT. A possible explanation for how LIT could have improved power at lactate threshold is increased expression of MCT1, which appears to facilitate intramuscular lactate transport [80, 81].

Unlike VO_{2max}, power at lactate threshold did show differences in improvements across time between the groups. Almost all of the improvement in W_{4mmol} occurred during the last 8 weeks of training in the TRAD group, while around one-third of the final improvement seen in the BLOCK group occurred after 4 weeks of training. The reason for the faster adaptation in the BLOCK group is unknown. A possible reason could be that the subjects were unfamiliar with training using block periodization, and the body adapted at a faster rate due to the novelty of the training organization. Another possible reason is that the greater stress to a factor being trained due to training in blocks may signal the body to adapt at a faster rate than in TRAD. Few previous studies on block periodization have tested power at lactate threshold during the training intervention. However, findings from Ronnestad et al. [59] and Garcia-Pallares et al. [69] are in agreement with the present findings. The BLOCK group in Ronnestad et al. [59] improved their power at 2 mmol/L blood lactate by $10 \pm 12\%$ after 4 weeks of training, while the TRAD showed no change. Garcia-Pallares et al. [69] did not measure power at lactate threshold but paddling speed at VT2, which improved by around 2.2% after the first 5 weeks of the BLOCK season. It is important to note, however, that Ronnestad et al. [72] found no difference between TRAD and BLOCK in power at 2 mmol/L blood lactate after 12 weeks of the same training performed in Ronnestad et al. [59]. Similarly, Garcia-Pallares et al. [69] found no difference in paddling speed at VT2 between the end of TRAD season and the end of the BLOCK season. These findings suggest that BLOCK periodization may be the best way to organize training for an athlete who needs to

improve in a short amount of time, but that TRAD and BLOCK periodization are equally effective for long term training adaptations.

4.2   Performance Indicators

4.2.1 Peak Power Output

Both TRAD and BLOCK led to improvements in W_{peak} in the present study and no significant differences between these improvements were found. The TRAD group improved their W_{peak} by $7.5 \pm 3.0\%$, while the block group improved by $8.4 \pm 6.9\%$. The change in W_{peak} correlated moderately with VO_{2max} ($r = 0.53$, $P = 0.00$) and low-moderately with the change in W_{4mmol} ($r = 0.37$, $P = 0.07$). This suggests that the improvements in W_{peak} were likely due to the improvements in VO_{2max} and power at lactate threshold. The magnitude of improvement in W_{peak} between TRAD and BLOCK was the same ($d = 0.1$). This suggests that how the training was organized did not have an influence on W_{peak}. This implies that stressing multiple factors as in traditional periodization and stressing a single factor as in block periodization are both viable strategies for improving W_{peak}.

The findings in the present study are similar to those reported in other block periodization studies. W_{peak} in Ronnestad et al. [74] improved by an estimated 6.2% after 12 weeks, and kayakers in Garcia-Pallares et al. [69] improved their W_{peak} by 5% after the TRAD season, and by 6.8% after the BLOCK season. Additionally, Storen et al. [73] reported an 8% improvement in W_{peak} following blocks of HIT. The findings of the present study differ, however, to Ronnestad et al. [72], in which only the BLOCK group exhibited improvements (6%) in W_{peak}. It possible that the TRAD group in Ronnestad et al. [72] showed no improvements in W_{peak} due to the considerably lower training volume performed compared to the present and previous studies mentioned. Another possible reason is that Ronnestad et al. [72] had more subjects than the previous studies mentioned, and that the previous studies had distorted findings due to low subject numbers.

As with VO_{2max}, differences in improvement of W_{peak} across time did not vary between the groups. Unlike VO_{2max}, around half of the final improvement in W_{peak} occurred during the first 4 weeks of training, while the other half occurred during the last 8 weeks for both TRAD and BLOCK. As mentioned earlier, the improvements in W_{peak} have been attributed to the

improved VO_{2max} and W_{4mmol} of the subjects in the present study. However, no significant improvements in VO_{2max} or W_{4mmol} were found after 4 weeks of training, suggesting that the improvement in W_{peak} during the first 4 weeks of training has to be explained by another reason. It is possible that greater muscle recruitment or improved synchrony of muscle activation may have led to the improvements in W_{peak}, although this was not tested. The findings of the present study differ slightly from Ronnestad et al. [59], which only found an improvement in W_{peak} in the BLOCK group after 4 weeks. The TRAD group in the present study most likely showed improvements in W_{peak} due to the considerably higher training volume compared to the TRAD group in Ronnestad et al. [59]. However, improvements in W_{peak} of 3-5% after 4-6 weeks have been reported in trained cyclists training with TRAD periodization [84-86]. Altogether, these findings seem to indicate that systematic block and traditional periodization lead to similar improvements of W_{peak} across time and that training volume may be an important factor in determining whether improvements in W_{peak} occur.

4.2.2 Power Output in 40-minute Time Trial

Both TRAD and BLOCK periodization led to improvements in W_{mean} in the 40-minute time trial (W_{40TT}). The TRAD group improved by $7.0 \pm 7.7\%$ while the block group improved by $5.8 \pm 6.4\%$ with no differences between the groups. Change in W_{40TT} correlated moderately with the change in W_{peak} ($r = 0.49$, $P = 0.01$) and highly with the change in W_{4mmol} ($r = 0.74$, $P = 0.00$). This suggests that the improvements in W_{peak} and W_{4mmol} were likely the main factors leading to improvements in W_{40TT}. Since the improvements in W_{peak} were moderately associated with the improvements in VO_{2max}, the improvement in W_{40TT} may also have been caused in part by the improvements in VO_{2max}. It is also of importance to note that a small association between W_{40TT} and cycling efficiency was found ($r = 0.32$, $P = 0.00$). This indicates that cycling efficiency appeared to influence time trial performance in the present study, and that time trial performance would likely have improved to a greater extent had cycling efficiency improved as well. As with VO_{2max}, power at lactate threshold, and W_{peak}, the magnitude of improvement in W_{40TT} was the same for both TRAD and BLOCK ($d = 0.16$). This suggests that traditional and systematic block periodization are equally effective at improving W_{40TT} too.

The findings in the present study are similar to those reported in Ronnestad et al. [72] when taking into account the large spread of improvement in the present study, in which the TRAD group improved by 4% and the BLOCK group by 8% with no significant difference between groups. This suggests that the way training is organized does not have a strong effect on performance in a 40-minute time trial. This also suggests that a training program that only block periodizes HIT is as effective as a systematic block periodization program at improving W_{40TT} since Ronnestad et al. [72] only block periodized HIT. Storen et al. [73] reported a 14.9% improvement in W_{mean} during a 15 km time trial after 1 year. The cyclist in this study trained using TRAD periodization for the first 8 months and HIT block periodization during the last 4 months. This case study seems to indicate that both the TRAD and BLOCK periodization were involved in improving W_{mean} in the time trial in Storen et al. (2012). This supports the finding of improved W_{40TT} for both the TRAD and BLOCK group in the present study.

4.3 Strengths and Weaknesses

There are several strengths in the present study. Firstly, the study was conducted at two different centers with different researchers collecting the data at each center. The fact that the study took place at multiple centers means that researcher bias was most likely controlled for and ecological validity increased in this study. Secondly, adherence to training was high in both TRAD and BLOCK groups, and subjects in the TRAD group did not train like subjects in the BLOCK group and vice versa. Additionally, both groups did not differ significantly in volume of LIT, MIT, and HIT performed. This means that any differences between the groups has to be due the different periodization models and not due to any differences in the volume of training at different intensities. Another strength of this study is that there was a large variety of fitness levels and ages in the subject population, which means that the findings of this study are applicable to a larger group of people. Furthermore, the present study conducted a mid-test, which allowed differences in improvement across time between TRAD and BLOCK to be tested. Lastly, this study tested both physiological and performance measures, which allowed the researcher to test the relationship between the differences in physiological measures and the differences in performance.

Although there are many strengths to the present study, there are also some weaknesses. Firstly, not all conditions at the pre-tests could be replicated at the mid- and post-tests. Some

subjects who performed their pre-tests in the morning had to perform their mid- and/or post-test in the evening due to work. Furthermore, the subjects in the study were amateur cyclists with jobs. Pre-testing took place after the Christmas break, meaning that the subjects were probably mentally fresher from being off work during the pre-test than during the mid- and post-test when they were working. It is possible that this could have led to reduced performance during the mid- and post-tests. Thirdly, some of the subjects became sick during the training intervention, meaning that the training sessions while they were sick or recovering from sickness would have been reduced in quality. This could have affected the subjects who became sick's results at the mid- and post-test. However, any influence of sickness on the results were likely controlled for given that there were 25 subjects. Another weakness was that volume of strength training during the training intervention was not controlled for. However, 1-RM showed no significant difference from pre- to post-tests.

4.4 Future Research

The findings from the present study raise new questions and suggestions for further research on block periodization for well-trained cyclists. Firstly, it would be of value to perform the present study with more subjects. Although 25 is the highest number of subjects for any block periodization training intervention study to date, more subjects could perhaps result in findings more in line with reality. Secondly, a training intervention study with multiple groups of different variations of block periodization would be useful for filling many of the gaps in knowledge we have regarding block periodization. Two of the groups would be the same as the present study, a systematic block group and a traditional group. The 3rd group would perform a single HIT block every 4 weeks as in Ronnestad et al. [72], while a 4th group would perform 1 LIT block, 2 HIT blocks, and 1 recovery week every 4 weeks. Such a study design would give answers to whether substituting a MIT block for another HIT block induces greater improvements than systematic block periodization and would test whether adding another HIT block per cycle induces greater improvements than previously reported. It would also be useful to have a control group that just performs LIT during the 12 weeks. This would provide more insight into the importance of LIT and how blocks of MIT and HIT effect physiological and performance factors. Lastly, in the instance where no differences are found between periodization models as in the present study, it would be useful measure the subject's weekly motivation and overall feeling of preparedness. Such information could potentially differentiate the effectiveness of different periodization models.

5 Conclusion

Systematic block periodization and traditional periodization of endurance training seems to have the same effectiveness at improving physiological and performance variables for well-trained cyclists during the preparatory period. Both periodization models led to similar improvements in VO_{2max}, W_{4mmol}, W_{peak}, and W_{40TT}. This finding seems to suggest that the overall content of a training program in the preparatory period is more important than how it is periodized in well-trained cyclists. Although the mechanism behind improvements in VO_{2max} cannot be explained in the present study, one can speculate that the improvements in VO_{2max} seen were most likely due to the HIT training, and that the improvements in power at lactate threshold followed the improved VO_{2max}. The improvements in W_{peak} seem to be associated with the improvements in VO_{2max} and power at lactate threshold, while the improvements in W_{40TT} appear to be associated with the increased W_{peak}. Cycling efficiency did not improve after 12 weeks of training for both the TRAD and BLOCK group, but systematic block periodization may be more effective than traditional periodization at improving cycling efficiency. A secondary finding was that traditional and systematic block periodization led to similar improvements across time in VO_{2max}, W_{peak}, and W_{40TT}, but not in W_{4mmol}, where systematic block periodization induced earlier improvements compared to traditional periodization. This means that systematic block periodization and traditional periodization are equally effective in the long-term, but that systematic block periodization may be superior at inducing improvement in the short-term. Improvements seen in the present study were generally less or equal to studies that only block periodized HIT, which raises the question of whether MIT blocks are necessary. It can be concluded from this study that both systematic block and traditional periodization are equally effective training organization strategies for well-trained cyclists during the preparatory period. Future research on block periodization should include more subjects and investigate more variations of block periodization.

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