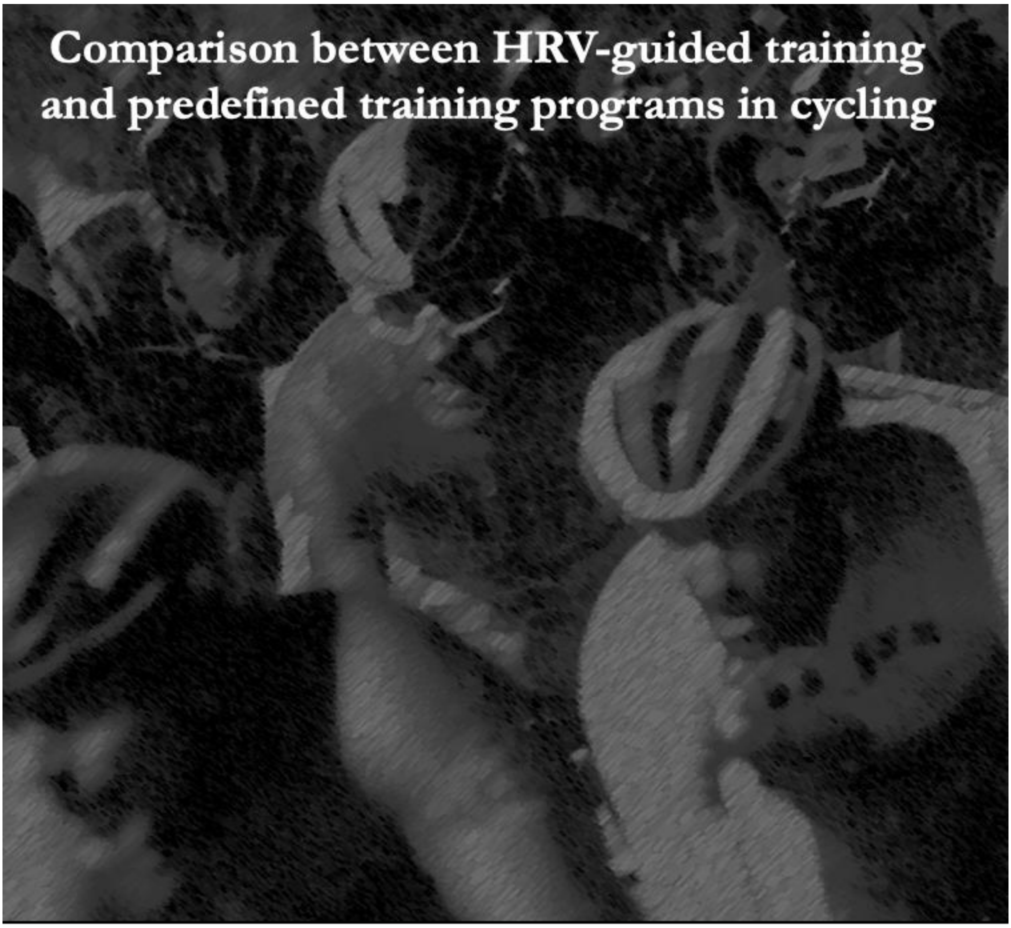
Comparison between HRV-guided training and predefined training programs in cycling



DOCTORAL THESIS

Alejandro Javaloyes Torres

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La presente tesis doctoral es un compendio de trabajos previamente publicados o aceptados para publicación:

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COMPARISON BETWEEN HRV-GUIDED TRAINING AND PREDEFINED TRAINING PROGRAMS IN CYCLING

Doctoral thesis

A dissertation presented by

Alejandro Javaloyes Torres

Elche, 2019

El Dr. Manuel Moya Ramón, profesor Contratado Doctor en la Universidad Miguel Hernández de Elche, hace constar que el trabajo de investigación titulado "COMPARISON BETWEEN HRV-GUIDED TRAINING AND PREDEFINED TRAINING PROGRAMS IN CYCLING" realizado por el doctorando D. Alejandro Javaloyes Torres, ha sido supervisado bajo su dirección y autorizado para su depósito y posterior defensa como Tesis Doctoral en esta Universidad ante el tribunal correspondiente.

Lo que firmo para los efectos oportunos en:

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AUTORIZA:

Que el trabajo de investigación titulado: "**Comparison between HRV-guided training and predefined training programs in cycling**" realizado por D. Alejandro Javaloyes Torres bajo la dirección del Dr. D. Manuel Moya Ramón, sea depositado y posteriormente defendido como Tesis Doctoral en esta Universidad ante el tribunal correspondiente.

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D. Alejandro Javaloyes Torres

Dirigida por el Dr. D. Manuel Moya Ramón

El director **El doctorando**

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PART THREE

Abstract

Training periodization is defined by the organization of training contents with the aim of achieving the best possible performance on selected dates. This includes different theories about how content should be organized to achieve this desired objective. The main limitation of predefined periodization models is that the response to training programs is highly individual. This response depends on many factors such as age, previous experience, sports level and history, among others. Even in athletes of similar level we can find different responses to the same training programs. Therefore, it is necessary to individualize and optimize these training programs based on this response in order to obtain the greatest increases in sports performance. In sports such as road cycling, with high training volumes and intensity, optimizing this training process can be key in the sporting success and the prevention of non-recommendable states of fatigue (such as non-functional overreaching). Despite this limitation, changes in a training program usually occur when the athlete's perception of fatigue does not match what is expected by the coach or physical trainer. A tool that allows to measure this response to training is heart rate variability (HRV). HRV is a valid, reliable measure of the autonomic nervous system. It has been demonstrated that HRV is able to detect the adaptation to the training and fatigue status of an athlete. Some studies have implemented HRV measures to guide training in endurance sports like running and cross-country skiing. The aims of this thesis are to investigate the effect of a training prescription guided by HRV in well-trained cyclists, observing the changes in fitness and performance, and to compare those results against different predefined training program theories in specific traditional and block periodization models. The main results of this thesis are: (1) The training prescription guided by HRV showed better increases in performance than predefined training programs. (2) The peak power output (calculated as the power at maximal oxygen consumption) improved with the training prescription guided by HRV while it presented beneficial effects for block periodization training (but lower than HRV-guided training) and it did not improve for the traditional periodization model. (3) The power output at the second ventilatory threshold improved in the three periodization models (HRV-guided training, block periodization and traditional periodization), being the traditional periodization the one that showed the fewer increments. (4) The power output at the first ventilatory threshold presented unclear results for HRV-guided training, showing significant changes in one study and not showing changes in the other. (5) The training volume and intensity were similar among all the periodization models, with the exception of the traditional model that showed moderate intensity most of the time (between the first and the second ventilatory thresholds). The main contributions of this thesis are: (I) The HRV-guided training is suitable to favour improvements in performance and fitness in the study population. (II) This HRV-guided training has been applied in an ecological design in road cycling. (III) This periodization model allows to determine an athlete's condition based on an objective physiological measurement that could be used to determine the most suitable type of training to favour a positive adaptation to training.

Keywords: endurance performance, individualization, applied physiology, aerobic fitness.

Resumen

La periodización del entrenamiento se define como la organización de los contenidos de entrenamiento con el propósito de conseguir el mejor rendimiento posible en la/s competición/es objetivo. Ésta comprende numerosas teorías acerca de cómo debieran organizarse los contenidos para alcanzar el objetivo propuesto. La principal limitación de los modelos de periodización predefinidos es que la respuesta a los programas de entrenamiento es altamente individual. Esta respuesta depende de muchos factores como la edad, la experiencia previa, el nivel deportivo y el historial, entre otros. Incluso en deportistas de nivel similar podemos encontrar respuestas diversas ante los mismos programas de entrenamiento. Por lo tanto, se hace necesario individualizar y optimizar estos programas de entrenamiento en base a esta respuesta, con el fin de obtener los mayores incrementos en el rendimiento deportivo. En deportes como el ciclismo de carretera, con volúmenes e intensidades muy elevados, optimizar este proceso de entrenamiento puede ser clave en el éxito deportivo y la prevención de estados no recomendables de fatiga (como el sobre-entrenamiento no funcional). A pesar de esta limitación, los cambios en un programa de entrenamiento suelen realizarse cuando la percepción de fatiga del deportista no concuerda con la esperada por el entrenador o preparador físico. Una herramienta que permite medir esta respuesta al entrenamiento es la variabilidad de la frecuencia cardiaca (HRV, del inglés *Heart Rate Variability*). La HRV es una medida no invasiva, válida y fiable del sistema nervioso autónomo. Numerosos estudios la han identificado como un reflector del efecto del entrenamiento, reflejando las adaptaciones al ejercicio, así como los estados de fatiga. Algunos estudios han implementado los registros de HRV para guiar el entrenamiento en deportes como la carrera a pie o el esquí de fondo. Los objetivos principales de esta tesis son investigar el efecto de una periodización guiada por mediciones de HRV en el entrenamiento en ciclistas entrenados, observando los cambios en la condición física y el rendimiento y comparándolos con diferentes modelos de entrenamiento predefinido, concretamente la periodización tradicional y por bloques. Los resultados de esta tesis son: (1) La periodización del entrenamiento guiada por HRV resultó en mejores incrementos en el rendimiento que los modelos de entrenamiento predefinido. (2) La potencia asociada al consumo máximo de oxígeno mejoró con la periodización del entrenamiento guiado por HRV, mientras que para el modelo de periodización por bloques mejoró en menor magnitud y para el modelo de entrenamiento tradicional no mejoró. (3) La potencia asociada al segundo umbral ventilatorio mejoró con los tres modelos de periodización del entrenamiento, siendo el modelo tradicional el que lo hizo con una menor magnitud de cambio. (4) La potencia asociada al umbral aeróbico presentó resultados contradictorios para el entrenamiento guiado por HRV, mostrando mejoras significativas en uno de los estudios y no mostrando cambios en el otro. (5) Los volúmenes de entrenamiento, así como la intensidad de los mismos, fueron similares entre todos los modelos de periodización, a excepción del modelo tradicional que presentó mayor proporción de entrenamiento a moderada intensidad (intensidad realizada entre los dos umbrales ventilatorios). Las principales aportaciones de esta tesis son: (I) Este modelo de periodización es apto para favorecer las mejoras en rendimiento y condición física en la población de estudio. (II) Los estudios se han llevado a cabo con un diseño ecológico aplicado al entrenamiento del ciclismo de carretera. (III) Este modelo de periodización permite determinar el estado del deportista en base a una medida fisiológica objetiva y de esta forma determinar el tipo de sesión de entrenamiento más adecuada para favorecer una adaptación positiva al ejercicio.

Palabras clave: rendimiento aeróbico, individualización, fisiología aplicada, fitness aeróbico

PART 1

1. GENERAL INTRODUCTION

1. General introduction

1.1 Principles of training periodization

Origin and evolution

In sport science, training periodization has been defined as a sequence of training units with the aim of obtaining the greatest performance during target competitions.[1] Although the sequencing of training process were carried out from the beginning of sport competitions, the first scientific publication that attempted to organize training is that by Matyeev.[2] His publications laid out the milestones of traditional periodization modelling by organizing training process into training units of different lengths. The traditional periodization model establishes the load-recovery process as the main concept to obtain increases in performance. This concept is based on the idea that stress is needed to achieve improvements in performance, but a proper recovery is crucial to illustrate these improvements. The annual cycle of the traditional periodization is divided into two main parts: the preparation period and the competitive period. These periods are subdivided into different time spans with different training orientations (table 1). The main characteristics of traditional training programmes are:

- Development of simultaneous multi-target training abilities.
- The training goes from high volume and low intensity to low volume and high intensity.
- One or two peak performances are allowed across an annual cycle.

However, the development and changes in sport has made the revision of the traditional periodization models necessary. These changes are:[3] 1. There is an increase in the number of competitions. 2. There is an increase in the economic benefit. 3. The advancement of sport science and the divulgation of the research in high-performance training. 4. The fight against banned pharmacological substances. 5. The development of new technologies with a direct application in daily practice.

Therefore, traditional periodization does not allow multi-peak performance during an annual cycle, which is a crucial factor in modern competitive sport, with a high number of competitions per season. In addition, high level athletes require a specific and intensive training to increase their performance. Thus, a multi-target training process does not provide an adequate stimulus to elucidate increases in performance. Furthermore, it could produce an excessive fatigue that could lead to non-functional overreaching. Nevertheless, traditional training programmes are suitable for sedentary and moderate trained populations as they have less training experience. Additionally, a multi-target training process will facilitate less monotony feeling in these populations.

Block periodization

Block periodization modelling appeared due to the evolution in sport competition and the failure of traditional periodization to develop the abilities of well-trained and elite athletes. The main premise of the block periodization model is to apply a concentrated training stimulus in a limited number of target abilities, normally one or two. The goal is to provide a sufficient intensive effect to produce an increase in fitness and performance. In addition, the training cycle is reduced. This fact allows to have more peaks in the performance throughout the annual cycle. Block periodization has been implemented in well-trained endurance and elite athletes in different sports: kayaking,[4,5] alpine skiing,[6,7] swimming[8] and road cycling.[9–11] It was concluded that block periodization reported greater increases in fitness and performance than a traditional periodization.[3] The main characteristics of block periodization models are:

- Every block is focused on a limited number of target abilities or training contents

- Target training is developed in a consecutive manner. This organization is the opposite of the traditional training programs, in which training abilities are prescribed simultaneously.
- Block duration lasts between 2 and 4 weeks

A training cycle is divided into three blocks: 1. Accumulation: development of basic abilities. 2. Transformation: intensive training focused on training targets directly related with performance (i.e. training focused on the anaerobic threshold development for road cycling). 3. Realization: training phase focused on recovery and taper. As a general consideration, every training cycled should last approximately 2 months, and a competition or trial must be prescribed at the end each of them.

The annual cycle is made up of between 5 and 7 training cycles. The duration of each cycle and their blocks could vary depending on the period of the season, the importance of the competition and other factors.

Training prescription in road cycling

Road cycling is an endurance sport that requires different abilities during racing. The performance in endurance disciplines is determined by the work economy and by aerobic performance, but it is also influenced by the anaerobic performance.[12] It has been suggested that work economy improves with long periods of low intensity training.[13,14] Regarding aerobic performance, it seems that a combination of low and high intensity training is needed for the development of endurance performance.[15,16] For this development, the optimal distribution of training plays a key role to ensure an optimal performance in target competitions. In this regard, block periodization has reported greater increases in fitness and performance in well-trained and elite cyclists than traditional training programs have.[9,11] As seen in other disciplines, concentrate workloads with limited training targets seems to be the best training organization to reach optimal increases in performance for highly trained populations.

Limitations of predefined periodization models

There is great scientific evidence that training programs lead to greater increases in fitness and performance than non-periodized training.[17–19] Nevertheless, periodization concepts are mostly based on coaches' self-experience and common sense acquired through years of experience.[20,21] These theoretical assumptions are deeply rooted in the training periodization models:[20]

- There is a correct order to develop training abilities.
- The training structures and their duration can be generalized across the same populations of athletes.
- Biological adaptation follows a predictable path.

Although all the training periodization models are based on the stress-recovery process and stress management, it has been shown that stress response is highly individual and dependent on a great number of circumstances.[21,22] Managing stress and recovery of predefined training programs in the field is generally done by the subjective criteria of the coach and the athlete. Although coaches play an extremely important role in monitoring athletes and know them really well, making decisions purely based on subjective data is challenging. Thus, predefined training periodization may not manage the stress properly because it does not register objective stress and fatigue measurements that support coaches experience and beliefs.

1.2 Monitoring stress and fatigue

The management of the stress-recovery process during a training period is one of the most important aspects when trying to reach optimal training adaptations. Generally, the significative stress imposed on an athlete results in fatigue. Fatigue is defined as the inability to complete a task that was achievable within a recent time frame.[23] Periodization models offer different time frame organizations for overload (increase of fatigue) and recovery periods (decrease of fatigue) in order to maximize the adaptation to training and subsequently they increase performance in key competitions. Although predefined training programmes do not consider measures of fatigue to evaluate the efficacy of the stress-recovery process, it has been suggested that measuring fatigue status could lead to a reduction of injury risk, illness and non-functional overreaching.[24] In addition, Thorpe et al (2011)[25] highlighted the importance of monitoring fatigue by selecting a combination of well-chosen diagnostic tests with smart sensor technology. Thus, the selection of proper tools to measure fatigue has prompted much attention for researchers and practitioners during recent years. There are a variety of tools to measure stress and fatigue in sport.[26]

First, there are athlete self-report measures that have been developed to assess the perceived well-being of athletes. Some examples are the POMS[27], TQR[28] or REST-Q[29] sport questionnaires. One limitation of the use of questionnaires on a daily basis is that are extensive.[25] For this reason, many practitioners use shorter customized questionnaires.

Second, maximal assessments have been suggested as a tool to detect the rate of recovery of performance: Maximal sprints, maximal voluntary contraction and jumps are examples of such tests, which are exhaustive and often difficult to implement in the daily routine of athletes. Different examples are the squat jump and the countermovement jump, which have been implemented in some studies[30] to evaluate the neuromuscular function after competition with decreases up to 72 h post-match.

Third, there has been some research carried out on biochemical parameters like different hormones and blood profile to understand their response to exercise. Besides, some markers are highly linked with fatigue (i.e. Creatine kinase levels increase after extenuating exercise)[26] and provide useful information, however, their use has a high economic cost and they are time consuming. In addition, these parameters are primarily obtained from invasive tests (like blood analysis). For these reasons, it is difficult to implement their use on a daily basis, and consequently, that they facilitate the decision-making process regarding training prescription.

The role of the autonomic nervous system in monitoring fatigue and adaptation

The autonomic nervous system (ANS) participates in the maintenance of the body's regulation and, therefore, it plays a key role in the management of the stress-recovery process.[31] ANS regulates involuntary processes like cardiac regulation, gastrointestinal responses to food, blood pressure or thermoregulation, etc.[32] ANS is divided into two branches with opposite functions: the sympathetic and parasympathetic or vagal branches. The sympathetic mediates the "fight or flight" response while the parasympathetic branch is predominant during resting situations (figure 1). Thus, depending on the situation, there is a predominance of one branch over the other and vice versa. During exercise, there is a predominance of the sympathetic branch producing an increase in heart rate, blood pressure, etc. Immediately after exercise, there is a parasympathetic reactivation with the aim of returning to baseline levels. In this regard, it has been shown that cardiac parasympathetic reactivation following exercise is dependent on training intensity:[33] Harder training sessions will produce cardiac parasympathetic reactivation delays of up to 48 h while low intensity training may produce disturbance of about 24 hours or less. However, cardiac autonomic regulation is highly individual and its daily measurement could be used as a tool for organizing microcycle distribution.[33] In addition, measures of parasympathetic cardiac regulation have been proposed as a measure of fatigue[34] and prediction of individual adaptation to endurance training:[35] Mid- and short-term parasympathetic decreases are related to fatigue while long-term parasympathetic increases are related with a positive adaptation to endurance training due to an increase in stroke volume.[34,36,37] Therefore, the measurement of the parasympathetic branch allows the management of stress and recovery on an individual basis.

ANS has been measured through cardiac autonomic regulation with different markers. Submaximal heart rate has been studied with training adaptation, showing that an increase in fitness and performance is related to decreases in submaximal heart rate. However, submaximal heart rate also decreases in over-reached athletes.[38]

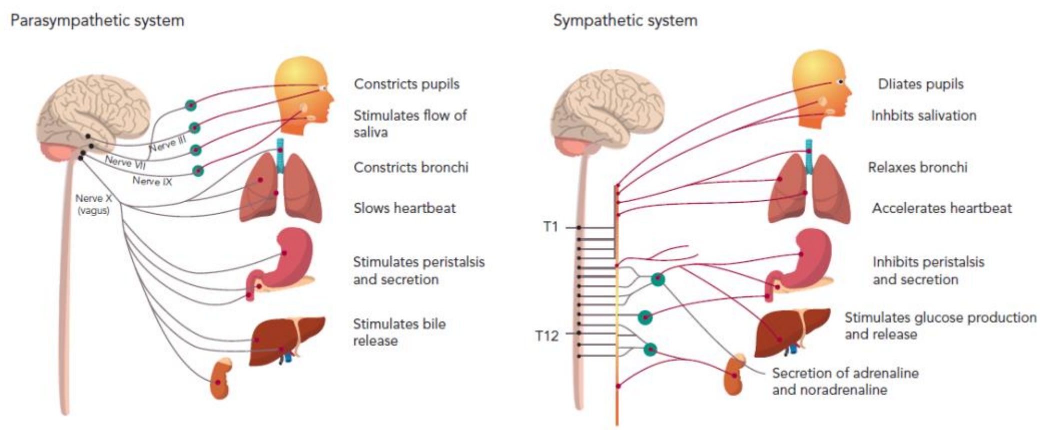


Figure 1. Anatomy of Parasympathetic and Sympathetic Nervous systems and their main functions on different organ systems.

Another variable studied for the assessment of cardiac autonomic regulation is heart rate recovery. Heart rate recovery after exercise shows the adjustment of the body by the sympathetic withdrawal and parasympathetic reactivation.[39] It has been shown that the heart rate recovery is affected by fatigue showing decreases after high intensity training.[40] In contrast to this, it seems that positive adaptation to training is not always related with an acceleration in heart rate recovery[41] and changes in this variable must be interpreted in accordance with the training context. As its assessment is performed immediately after the training session, its usefulness to assess fatigue is limited to a daily basis. Therefore, there is a need for a non-invasive and easily obtained measure that can evaluate the athlete daily before the training session.

Heart rate variability (HRV) has been proposed as a non-invasive tool to measure the cardiac autonomic regulation. HRV is defined by the measurement variation between

R-R intervals resulting from sinus node depolarizations during a continuous electrocardiogram recording.[42] Several variables are derived from this recording by linear (time- and frequency-domain) and non-linear methods (see table 1). HRV measurements have been implemented in sport science for several purposes such as the evaluation of short-[38,43] and long-term[44,45] fatigue of athletes, to estimate ventilatory thresholds,[46,47] to identify functional and non-functional overreaching,[48] to determine pre-competitive anxiety and cognitive performance[49] and to observe positive and negative adaptation to training among others.[35,50–52] Although we have mentioned the most common variables for the measurement of HRV, two of them are worth mentioning due to their extensive use to monitor the effects of endurance exercise and fatigue:[34] the high frequency power (HF) and the square root of the mean squared differences of successive R- R intervals (RMSSD). Both variables are vagal-related variables that are commonly measured during rest in standardized conditions. It has been suggested that the parasympathetic branch reflects the positive and negative adaptation to training with increases and decreases of those vagal-related variables respectively.[53,54]

It has been demonstrated that HF is able to detect fatigue[48] in endurance athlete as well as positive and negative adaptation to training.[55] However, to obtain valid and reliable recordings there are some methodological considerations that must be taken it into account. For example, HF is influenced by breathing frequency[42] and needs to be properly controlled (with a metronome) and needs a higher length of recording than other HRV variables (a length between 3 and 4 min).[56] For these reasons, athletes are less likely to perform such recordings on a daily basis with these considerations because they are time consuming.

The RMSSD has been proposed as a valid and reliable index to measure the cardiac parasympathetic branch. It has been shown that the RMSSD is a reliable marker of training status.[34,53,57] In addition, it does not report changes due to breath pacing[58] and it can be measured in short recordings (< 5 min).[59,60] These conditions facilitate its usefulness in monitoring HRV on a daily basis. In recent years, the development of new technologies, such as smartphone applications,[61,62] has allowed the registering of HRV on a daily basis producing minimal disturbances in the athletes.

Table 1. Heart variability indexes.

	Variable	Description
Time-domain	Mean RR	Mean R to R interval
	SDNN	Standard deviation of R to R interval
	RMSSD	The square root of the mean squared differences of successive R to R intervals
	pNN50	The mean number of times an hour in which the change in successive normal sinus (NN) intervals exceeds 50 ms.
Frequency domain	VLF	Very low frequency (0.00-0.04 Hz)
	LF	Low frequency (0.04-0.15 Hz)
	HF	High frequency (0.15-0.40 Hz)
	LF/HF	Ratio

RMSSD has been successfully implemented to evaluate positive adaptations to endurance training and non-functional overreaching as well as readiness-to-perform in elite endurance athletes.[54,63–65]

HRV enables the possibility of guided training workload distribution to favour optimal increases in performance and positive adaptations to training. In this regard, day-to-day training prescription has been previously compared with predefined training programmes in recreational and moderate training runners[66–68] and in untrained population.[69]

Despite the possibilities of day-to-day training prescription, this model has not been implemented in highly trained populations such as well-trained and elite road cyclists. This endurance sport showed high physiological demands both in race and in training. Due to its competitive calendar (from 40 days of competition for amateur under-23 cyclists to up to 80 days of competition for professional cyclists) there are little periods of time to improve fitness and performance during training (8 to 12 weeks between target competitions). The implementation of day-to-day training could be a better option than predefined training programmes to improve performance for this population as they do not have much room for further development of their capabilities.

To date, there is no evidence of the implementation of day-to-day training in road cycling. The main purposes of this thesis are the comparison of day-to-day training prescription against most common predefined training programmes: a traditional periodization (study 1) and a block periodization (study 2). The specific aims and purposes are detailed in chapter 2: Purposes and hypothesis of the thesis.

2. PURPOSES AND HYPOTHESIS OF THE THESIS

2. Purposes and hypothesis of the thesis

2.1 Purposes

To compare the changes in fitness between a traditional training programme of multi-target training abilities (low, moderate and high-intensity training) and a training prescription guided by HRV in well-trained cyclists.

To compare the changes in performance between a traditional training programme of multi-target training abilities (low, moderate and high-intensity training) and a training prescription guided by HRV in well-trained cyclists.

To observe if training intensity distribution differs between a traditional training programme of multi-target training abilities and a training prescription guided by HRV in well-trained cyclists.

To compare the changes in fitness between a block periodization training programme of low and high-intensity training against a training prescription guided by HRV in well-trained cyclists.

To compare the changes in performance between a block periodization training programme of low and high-intensity training against a training prescription guided by HRV in well-trained cyclists.

To observe if training intensity distribution differs between a block periodization model and a training prescription guided by HRV in well-trained cyclists.

2.2 Hypothesis

The training prescription guided by HRV will produce greater increases in fitness than a traditional training programme of multi-target training abilities.

The training prescription guided by HRV will produce greater increases in performance than a traditional training programme of multi-target training abilities.

A traditional training programme of multi-target training abilities will show a greater proportion of moderate training than a training prescription guided by HRV.

The training prescription guided by HRV will produce greater increases in fitness than a block periodization.

The training prescription guided by HRV will produce greater increases in performance than a block periodization.

A block periodization will show a greater proportion of high-intensity training than a training prescription guided by HRV.

3. SUMMARY OF THE METHODS

3. Summary of the methods

3.1 Participants

The participants that took part in the studies accomplished within this thesis were categorised as well-trained cyclists based on the classification of De Pauw et al.[70] A total of 37 participants divided into two different experimental designs participated in this thesis. The participants had a previous training experience in road cycling of at least 5 years with 2 years of personalized training program. Before taking part in the study, all participants were fully informed about the study and had to sign a written informed consent. The study was approved by the ethical committee of the Miguel Hernandez University and it was conducted conforming to the recommendations of the Declaration of Helsinki.

3.2 Experimental designs

Similar experimental designs were carried out for both studies with slight differences that are described below. In summary, both studies were divided into two periods:

A first period of standardized training for the participants. The purpose of this period was for the participants to familiarize themselves with the procedures (typical training sessions, usage of mobile apps to monitor training and HRV) and to establish resting HRV values. These periods lasted 4 and 2 weeks in the first and second study, respectively.

A second period in which the participants were divided into two groups in each study: a predefined training group and an HRV-guided training group (HRV-G).

There was an assessment evaluation week before and after each period, making up a total number of three evaluations (PRE, MID and POST).

3.3 General procedures

Training prescription during the baseline weeks was the same for the participants in each group in each study. After the baseline period (BW), the participants were divided into two groups: one group that followed a predefined training program and a second group that followed a training prescription guided by daily HRV measurements during 8 weeks (TW). The specific training programs followed by the participants are described in the studies (chapter 7 and 8). In the first study (chapter 7), participants that were allocated in the predefined training group followed a multi-targeted (low, moderate and high intensity training sessions) traditional training programme with progressive increment of training intensity (TRAD). In the second study, the predefined training group performed a training block periodization (BP) of high intensity training (chapter 8).

Two different tests were assessed during the evaluation weeks (EW) with the aim of measuring fitness and performance: a graded exercise test (GXT) and a 40-minute time-trial (40TT). Both tests were performed in the same laboratory under the same conditions. Furthermore, the tests were carried out on the participants' own bicycle placed in a Wahoo Kickr ergometer.[71] Both tests (GXT and 40TT) were separated by at least 48 hours.

First, a GXT to assess VO_2max and the first (VT1) and second (VT2) ventilatory thresholds. Peak power output (PPO), Power at VT1 (WVT1) and Power output at VT2 (WVT2) were also calculated derived from the GXT test. The methodology was the same in all the GXT test performed:

- A standardized 10 minute warm-up of at 50 W. The ergometer was calibrated during this period according to the manufacturer’s instructions.
- Test until exhaustion consisting of 25 $W \cdot min^{-1}$ increase.[72] The graded exercise test terminated when a cyclist’s cadence dropped more than 10 rounds per minute (rpm) below their preferred cadence for more than 10 seconds.

Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) was measured continuously during the GXT with the MasterScreen CPX (Jaeger Leibniztrasse 7, 97204 Hoechberg, Germany). VO_2max was calculated as the highest 30 second VO_2 average. Two independent researchers determined the ventilatory thresholds by direct observation of the equivalents of oxygen and carbon dioxide (VE/VO_2 and VE/VCO_2, respectively) and end-tidal pressure of oxygen ($PETO_2$).[73] In case of discrepancy, a third investigator determined the ventilatory thresholds in order to select the correct one. The criteria followed for their detection (Annex 1) was:

- VT1: An increase in VE/VO_2 and $P_{ET}O_2$
- VT2: An increase in both the VE/VO_2 and VE/VCO_2 and a decrease of $P_{ET}O_2$

Second, participants performed a 40TT to establish performance. The average power output was recorded. Participants were able to drink *ad libitum*. Verbal encouragement during the 40TT was given by researchers and all feedback during the testing was blinded from the cyclists with the exception of accumulated time.

The HRV was measured daily. All participants were instructed to measure their R-R interval data after waking up and emptying their bladder, both during the BW and the TW period. HRV was measured in a supine position and over a 90 s period.[59] Cyclists were instructed to lie still and not to perform any further activity during the recordings and the last 60 s of the HRV measurement were captured.[74] The RMSSD was chosen as the vagal index, based on its greater suitability and reliability than other indexes. The HRV data was transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution.[57] A 7-day rolling average ($LnRMSSD_{7day\text{-}roll\text{-}avg}$) was calculated for the purpose of training prescription.[54] During the baseline weeks, the smallest worthwhile change (SWC) of LnRMSSD was calculated as mean ± 0.5 x SD.19 This SWC was used for the interpretation of changes in $LnRMSSD_{7day\text{-}roll\text{-}avg}$ during the following 4 weeks. The basic idea for the

HRV guided training group was to cease high intensity training when $LnRMSSD_{7day-roll-avg}$ fell outside the SWC. The SWC was updated every after the first 4 weeks of TW due to the relationship between CAR and the adaptation to training.[34]

3.4 Statistical analysis

Prior to the analysis, the homogeneity of the data was tested using the Levene's test while the normal distribution was checked using a Shapiro-Wilk test. The statistical analyses were very similar in the studies that are part of this thesis. The analysis of the changes in the different variables and groups was done with two different statistical techniques. A repeated measure of analysis of variance followed by a Bonferroni post hoc test was performed to detect both within- and between-group changes. Level of significance was set at $p < 0.05$.

In addition to this analysis, a magnitude base inference (MBI) was performed to assess practical significance.[75] MBI consists of the comparison of the standardized change in Cohen's *d* units. The SWC was set at $d = 0.2$. In addition, the chances that any change was greater/similar/smaller within- and between-groups was calculated using effect size and the 90% confidence limits (CL). Then, the qualitative assessment of the magnitude of change was established as follows: most unlikely (<0.5%); very unlikely (0.5 to 5%); unlikely (5 to 25%); possible (25 to 75%); likely (75 to 95%); very likely (95 to 99.5%); most likely (>99.5%).[75]

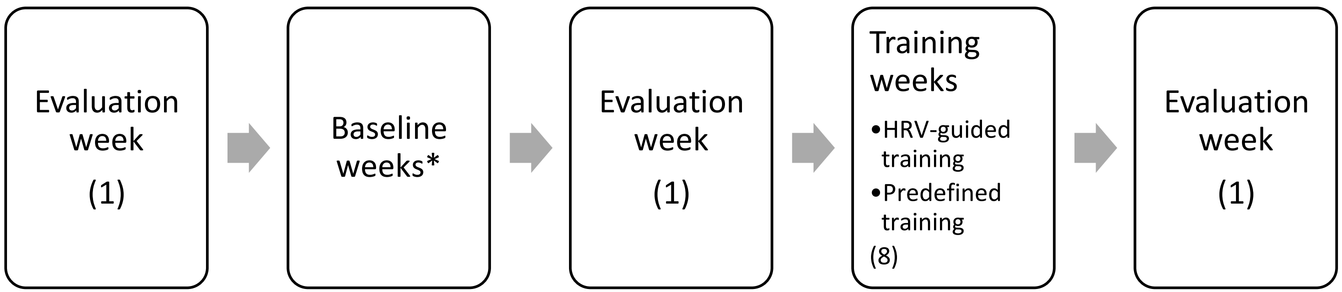


Figure 2. Experimental design followed in the studies. The numbers in parentheses represent the number of weeks.

*Baseline week lengths were different between studies: 4 and 2 weeks for study 1 and 2, respectively.

4. SUMMARY OF THE RESULTS

4. Summary of the results

This chapter summarizes the main results obtained in the studies presented in this thesis. The main results are that the changes in fitness and performance were greater in most of the variables measured in the HRV-guided training groups than in the groups that performed a predefined training program. Statistical significance, effect size, standardized differences, practical significance and qualitative assessment are displayed in the results section of chapters 7 and 8.

4.1 Training

Training volume did not differ either in study 1 (8 h 17 m ± 2 h 48 min for HRV-G and 8 h 13 m ± 2 h 42 min for TRAD) nor in study 2 (11 h 06 m ± 3 h 04 m for HRV-G and 11 h 22 m ± 3 h 07 m for BP).

Training intensity distribution was different between groups in the moderate intensity domain in study 1 while it remained similar in study 2. There were no differences between low and high intensity training between predefined and HRV-guided training in the studies (Figure 3).

4.2 Within-group differences

In study 1, VO_2max remained similar after TW in HRV-G (MID: 56.34 ± 7.58; POST: 55.8 ± 8.18) and TRAD (MID: 54.30 ± 7.81; POST: 52.13 ± 6.78). MBI reported unlikely beneficial and very unlikely beneficial effects for HRV-G and TRAD, respectively. Study 2 showed significant increases for HRV-G (MID: 58.94 ± 5.62; POST: 61.04 ± 6.01) while BP did not (MID: 58.96 ± 6.23; POST: 62.65 ± 6.65). In contrast, MBI showed likely beneficial effects for HRV-G and BP in study 2.

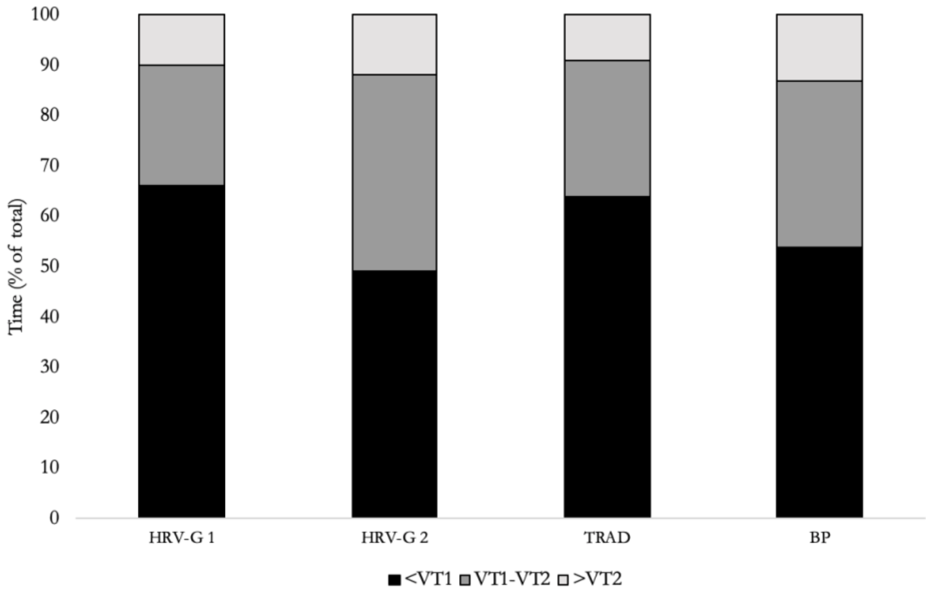


Figure 3. Training intensity distribution during training weeks (TW) in the groups that participated in the studies.

VT1 and VT2: First and second ventilatory thresholds.

In study 1, PPO significantly improved in HRV-G (MID: 356.83 ± 39.74; POST: 374.28 ± 43.65) but not in TRAD (MID: 346.75 ± 16.73; POST: 351.50 ± 17.01). MBI showed likely beneficial and unclear results for HRV-G and TRAD, respectively. On the other hand, study 2 showed significant increases for HRV-G (MID: 395 ± 39; POST: 423 ± 28) but not in BP (MID: 388 ± 42; POST: 407 ± 51) while MBI reported very likely beneficial and possibly beneficial effects for HRV-G and BP.

WVT2 improved in HRV-G (MID: 395 ± 39; POST: 423 ± 28) and TRAD (MID: 395 ± 39; POST: 423 ± 28) in study 1, with most likely beneficial and very likely beneficial effects, respectively. In study 2, HRV-G (MID: 395 ± 39; POST: 423 ± 28) and BP (MID: 395 ± 39; POST: 423 ± 28) improved significantly with very likely beneficial effects.

In study 1, WVT1 did not report significant changes in HRV-G (MID: 191.67 ± 27.95; POST: 200.00 ± 25.01) and TRAD (MID: 175.00 ± 23.15; POST: 178.13 ± 28.15). However, MBI showed possibly beneficial effects in HRV-G while TRAD showed unclear standardised changes. In study 2, WVT1 showed significant increases for HRV-G (MID: 170 ± 37; POST: 234 ± 30) but not in BP (MID: 188 ± 29; POST: 190 ± 42). MBI showed very likely beneficial and unclear effects.

In study 1, the 40TT improved in HRV-G (MID: 243.11 ± 41.73; POST: 260.78 ± 44.76) but not in TRAD (MID: 214.42 ± 32.36; POST: 223.13 ± 36.15). Furthermore, MBI showed very likely beneficial and possibly beneficial effects for HRV-G and TRAD, respectively. In study 2, HRV-G improved (MID: 261 ± 28; POST: 280 ± 39) while BP remained similar (MID: 262 ± 30; POST: 264 ± 33). MBI reported likely beneficial and possibly trivial effects for HRV-G and BP.

4.3 Between group differences

In the studies of this thesis and for all the variables measured during the EW (VO_2max, PPO, WVT1, WVT2 and the 40TT) there were no differences between-groups in PRE, MID and POST. In study 1, MBI showed possibly beneficial effects for HRV-G against TRAD in PPO and WVT2 and likely beneficial effects in the 40TT for HRV-G. In contrast, between-group practical significance and qualitative assessment during the TW showed unclear results in study 2.

5. SUMMARY OF THE DISCUSSION

5. Summary of the discussion

The studies comprised in this thesis aimed at determining the influence of HRV-guided training prescription on fitness and performance in well-trained cyclists and to compare these changes against the most common predefined training theories. To date and to the best of our knowledge, these studies are the first to implement HRV measurements into a training program in road cycling. As previously described in the summary of methods (chapter 3), different evaluations were performed in order to evaluate the changes in fitness and performance: graded exercises tests and a 40-min time-trial.

The major findings were that training prescription guided by daily HRV measurements could be implemented in well-trained road cyclists. When compared against the most common predefined training programs (traditional and block periodization), HRV-guided training elicited better increases in fitness and performance in most of the variables measured.

The main purpose of this chapter is to present a brief summary of the discussion. Nonetheless, the results presented in both studies are thoroughly discussed in the specific discussion section in chapters 7 (study 1) and 8 (study 2).

5.1 Training

Training volume was similar between groups both in the first and in the second study. Regarding training intensity, in study 1 (chapter 7) the proportion of time expended at moderate intensity domain (between VT1 and VT2) was lower for HRV-G. This result is in accordance with those previously reported.[69] It is possible that this result could be explained by the decision-making schema that could provide a more polarized intensity distribution. In study 2, training intensity was similar between groups, and consequently, the differences between groups are attributed to the distribution of training.

5.1 Changes in fitness

VO_2max did not change in study 1 while previous literature reported beneficial effects for a HRV-guided training.[66,68] This could be due to the participants´ level because previous studies were carried out with untrained and recreational athletes while our study was with cyclists with higher training experience. In contrast, study 2 reported changes for both groups. Regarding HRV-G, these results agree with previously research that reported increases in VO_2max.[35,76]. In study 2, block periodization reported beneficial effects in VO_2max,[9,11,77] thus, our results supported the previous research. The differences between the studies of study 1 and 2 could be because the proportion of high intensity training was greater in study 2.

PPO improved in HRV-G but not in the predefined training programs in both studies. In addition, MBI showed very likely beneficial effects in HRV-G while study 1 and 2 reported unclear and possibly beneficial effects for TRAD and BP, respectively. Since the volume and high intensity of the training were similar between groups and high intensity training was prescribed when $LnRMSSD_{7day\text{-}roll\text{-}avg}$ was within SWC, a possible hypothesis is that HRV-guided training allows a better timing in the prescription of high intensity training.

Although the average training intensity in road cycling is expended around the aerobic threshold,[78,79] the competitive situations that have a major impact on the result of a race are mountain passes and time-trials that are performed around the anaerobic threshold. The WVT2 showed significant increases for both groups in study 1 and 2. Thus, it seems that both HRV-guided training and predefined training programmes are able to improve this variable. However, MBI and its qualitative assessment showed a more positive response for HRV-guided training than predefined training. Thus, it seems that HRV-guided training could optimize the improvements in WVT2.

WVT1 showed different responses in study 1 and 2. In study 1, WVT1 did not show positive or negative changes; in addition, MBI reported possibly beneficial effects for

HRV-G while TRAD reported unclear changes. Another study reported beneficial effects for HRV-G[67]. However, the mentioned study also prescribed strength training that may explain the discrepancies with our results. In study 2, WVT1 increased in the HRV-G but not in the BP group. Furthermore, magnitude-based inference reported larger improvement in the HRV-G group than in the BP group in this variable with very likely beneficial and unclear assessment for the HRV-G and the BP groups.

5.2 Changes in performance

In this thesis, the performance was measured with a 40TT. In both studies, the power output in this test was performed between VT1 and VT2. Study 1 reported significant changes for HRV-G while it remained similar in TRAD. Furthermore, MBI showed higher magnitude of change in HRV-G than in TRAD. These results are in line with those reported previously that supported HRV-guided training against traditional predefined training programs.[66,68] Study 2 compared the HRV-guided training and a block periodization. The 40TT improved in HRV-G but not in BP. In addition, MBI and qualitative assessment reported likely beneficial effects for the HRV-G while in the BP group it reported possibly trivial effects. To the best of our knowledge, only one study[67] which compared an HRV-guided training program and a block periodization found similar results.

Regarding these results, it seems that HRV-guided training could be more effective to improve the performance in well-trained cyclists than predefined training programs.

6. CONCLUSIONS OF THE THESIS

6. Conclusions of the thesis

6.1 General conclusions

The main conclusions of this thesis are summarized in the following points:

- Prescribing moderate- and high-intensity training according to HRV daily measurements could be more effective to improve fitness and performance than traditional training prescription based on a predetermined training load in a relatively short period of time (Study 1).
- Despite a lower proportion of time at moderate intensity, the HRV-guided group had greater increments in performance (40TT). It is worth to mention that the 40TT intensity was performed in the moderate intensity domain (between the first and second ventilatory thresholds) (Study 1).
- Prescribing high-intensity training according to HRV daily measurements showed a more positive response at improving fitness and performance than a block periodization (Study 2).
- Training loads were similar between HRV-guided training and block periodization. Therefore, the changes in fitness and performance are attributed to the distribution of the training (Study 2).
- The variability in the training response was reduced in the HRV-guided training group because most of the subjects in this group had a beneficial adaptation to training while the predefined training groups had a more heterogeneous response (Studies 1 and 2).
- Monitoring HRV on a daily basis may provide useful information on adaptation and fatigue in athletes. Therefore, the use of HRV to guide training gives greater insights into optimizing training to enhance performance in well-trained cyclists than predefined training programs (Studies 1 and 2).

6.2 Conclusiones generales

Las principales conclusiones que se pueden extraer de esta tesis las podemos resumir en los siguientes puntos:

- Prescribir entrenamientos de moderada y alta intensidad en función de los registros diarios de HRV podría ser más efectivo que una periodización tradicional para mejorar el fitness o condición física y el rendimiento en ciclistas entrenados (estudio 1).
- El entrenamiento guiado por HRV tuvo mayores mejoras en el rendimiento (40TT) a pesar de un menor volumen de entrenamiento a moderada intensidad que el entrenamiento tradicional. La intensidad media a la que se realizó esta prueba fue en esta zona específica (estudio 1).
- Prescribir entrenamientos de alta intensidad en función de los registros diarios de HRV mostró efectos más positivos que una periodización por bloques para mejorar el fitness o condición física y el rendimiento en ciclistas entrenados (estudio 2).
- La carga de entrenamiento fue similar en los dos grupos de estudio. Por lo tanto, las mayores mejoras para el grupo de entrenamiento guiado por HRV son atribuidas a la distribución de las sesiones.
- La variabilidad en la respuesta al entrenamiento fue menor en los grupos que entrenaron en función de los registros diarios de HRV que el los que tuvieron un entrenamiento predefinido (estudios 1 y 2)
- Monitorizar la HRV de forma diaria puede proporcionar información útil sobre la fatiga y adaptación de los deportistas. Por lo tanto, el uso de la HRV para guiar el entrenamiento permitirá una optimización del proceso de entrenamiento, obteniendo mejoras en el rendimiento en ciclistas entrenados (estudios 1 y 2)

6.3 Thesis limitations and future directions

The studies that make up this thesis show some limitations that must be mentioned:

The SWC was calculated in both studies with the same criterion (mean HRV over the previous 4 weeks ± (0.5 x Standard deviation of HRV of the previous 4 weeks) although changes in HRV are highly individual. Although this calculation has been adopted by the research in the field, more research is needed in order to individualize this calculation. This individualization needs to adapt either the range of the formula or the length of the data needed for its calculation.

The intervention period lasted 8 weeks. Although this study length is the typical shown in this type of research, our findings are difficult to apply during a complete cycling season. Nevertheless, the studies presented in this thesis are designed to be implemented in intensified training periods. A possible future research should apply the training guided by HRV in a complete season with different training purposes, and consequently, different decision-making algorithms.

The cyclists in the studies were well-trained athletes. To the best of our knowledge, this type of training has not been applied in professional cycling with less room for improvements of performance.

The day-to-day training is based only on daily HRV measurements. Being the perception of the athlete of great importance, it would be interesting to include within the model the perception of fatigue of the athlete. In this way decisions can be made based on two measures (objective and subjective).

PART 2

7. TRAINING PRESCRIPTION GUIDED BY HEART RATE VARIABILITY IN CYCLING

The study was previously published as:

Javaloyes A, Sarabia JM, Lamberts RP, Moya-Ramon M. **Training Prescription Guided by Heart Rate Variability in Cycling (2019).** *Int J Sports Physiol Perform.* 2018:1-28. DOI: 10.1123/ijspp.2018-0122

The journal is indexed in the Journal Citation Reports with an impact factor of 3,384 (2017) and is ranked 10 out of 81 in the category of sports sciences.

7. Training prescription guided by heart rate variability in cycling

Abstract

Road cycling is a sport with extreme physiological demands. Therefore, there is a need to find new strategies to improve performance. Heart rate variability (HRV) has been suggested as an effective alternative for prescribing training load against predefined training programs. The purpose of this study is to examine the effect of training prescription based on HRV in road cycling performance. Seventeen well-trained cyclists participated in this study. After an initial evaluation week (EW), cyclists performed 4 baseline weeks (BW) of standardized training to establish their resting HRV. Then, cyclists were divided into two groups, a HRV-guided group (HRV-G) and a traditional periodization group (TRAD) and they carried out 8 training weeks (TW). Cyclists performed two EW, after and before TW. During the EW, cyclists performed: (1) a graded exercise test to assess VO_2max, peak power output (PPO) and ventilatory thresholds with their corresponding power output (VT1, VT2, WVT1, and WVT2, respectively) and (2) a 40-min simulated time-trial. HRV-G improved PPO (5.1 ± 4.5 %; $p = 0.024$), WVT2 (13.9 ± 8.8 %; $p = 0.004$) and 40TT (7.3 ± 4.5 %; $p = 0.005$). VO_2max and WVT1 remained similar. TRAD did not improve significantly after TW. There were no differences between groups. However, magnitude-based inference analysis showed likely beneficial and possibly beneficial effects for HRV-G instead of TRAD in 40TT and PPO, respectively. Daily training prescription based on HRV could result in a better performance enhancement than a traditional periodization in well-trained cyclists.

Keywords: HRV; road cycling; periodization; endurance training; exercise performance

Introduction

Road cycling is considered to be one of the hardest endurance sports in the world,[80] with high physiological demands during training and competition.[65,81,82] Professional cyclists often accumulate up to 90 days of competitive racing within a season, which makes maintaining a healthy balance training/racing load and taking sufficient recovery time a challenge. Large gains in training status are generally achieved by prescribing high training loads followed by a minimal, but sufficient, recovery period.[35] Maintaining this balance is challenging as multiple factors such as training intensity, quality of sleep, nutrition, psychological well-being might vary substantially at an individual basis.[68]

Monitoring individual responses to training is, therefore, an important key factor to prescribe to most effective training programs.[24] A promising variable that is able to reflect positive or negative training adaptation is cardiac autonomic regulation (CAR).[34] This is supported by Lamberts et al.[83] who showed that cyclists who adapted well to high intensity training (HIT) had a faster heart rate recovery (HRR) response than cyclists that did not responds well to the HIT. In general, a decreased training status is associated with a lower power output at the same submaximal heart rate and a slower HRR, while an increased training status is associated with an increased power output the same submaximal heart rate and a faster HRR.[84] Confusingly and counterintuitively, functional overreaching and acute fatigue are associated with increased power at the same submaximal heart rate and a faster HRR (similar to an improved training status), but in contrast to an improved training, status is associated with increased RPE levels.[85,86] This counterintuitive response highlights the importance of monitoring properly as without the RPE data functional overreaching might be interpreted as an improvement in training status.

In addition to HRR, heart rate variability (HRV), which focusses on the variability of successive R-R intervals, also gained popularity in monitoring the training status of endurance athletes.[34,63–65] This tool enables the detection of fatigue status and assesses the adaptation to training. After high intensity training or a short-term overreached period, there is a decrease in the resting HRV values, reflecting the effect of the fatigue.[87,88] In addition, the increase of the performance after a training period is related to an increase in resting HRV.

However, these promising results of monitoring athletes only a few studies[66,68,89] have looked at using CAR markers to prescribe or regulate exercise prescription. This HRV-guided training, also called Day-to-Day periodization, allows new possibilities for the training load prescription according to an athlete´s status, the response to the training load and the adaptation to training. Although Day-to-Day periodization has been tested in endurance sports such as running[66,68,69] and cross-country skiing,[90] this new training prescription strategy has not been used in road cycling yet. Therefore, the purpose of this study was to determine the effect of a HRV-guided and a traditionally periodized training program on road cycling performance.

Method

Subjects

Seventeen trained cyclists with at least a personalised training history of 2 years were recruited from local clubs. The general characteristics of the participants are shown in Table 2, while the average cycling experience was 13 ± 10 years. Before taking part in the study, all participants were fully informed about the study and had to sign a written informed consent. The study was approved by the ethical committee of Miguel Hernandez University and was conducted conform the recommendations of the Declaration of Helsinki.

Table 2. Participant characteristics in PRE.

	HRV-G (n = 9)	TRAD (n = 8)
Age (years)	39.22 ± 5.33	37.62 ± 7.09
Experience (years)	12.33 ± 9.67	13.25 ± 10.02
Height (m)	1.76 ± 0.05	1.76 ± 0.06
Weight (kg)	76.92 ± 12.46	78.67 ± 11.72
VO_2max ()	55.04 ± 7.58	52.16 ± 6.50
PPO (W)	338.89 ± 39.75	335.13 ± 22.65
WVT2 (W)	253.13 ± 16.02	263.89 ± 37.73
WVT1 (W)	188.89 ± 25.35	175.00 ± 23.15
40TT (W)	231.89 ± 38.18	206.51 ± 31.55

PPO: Peak power output

WVT2: Power output at VT2 intensity

WVT1: Power output at VT1 intensity

40TT: Power output during the 40-min time-trial

Design

The study protocol was divided into two periods; i) a baseline period (BW) and ii) a training period (TW) (see also figure 4). The BW existed of 4 weeks base training which functioned as a standardization period after which a baseline HRV measurement could be captured. After the BW, cyclists were randomly assigned to a HRV-guided training group (HRV-G, n=9) or a traditional periodization training group (TRAD, n=8). During the following 8 weeks, the cyclists trained based to the group they were allocated to. Cyclists in the HRV-G trained according to their HRV morning values, while TRAD cyclists trained based on a predetermined training programme.

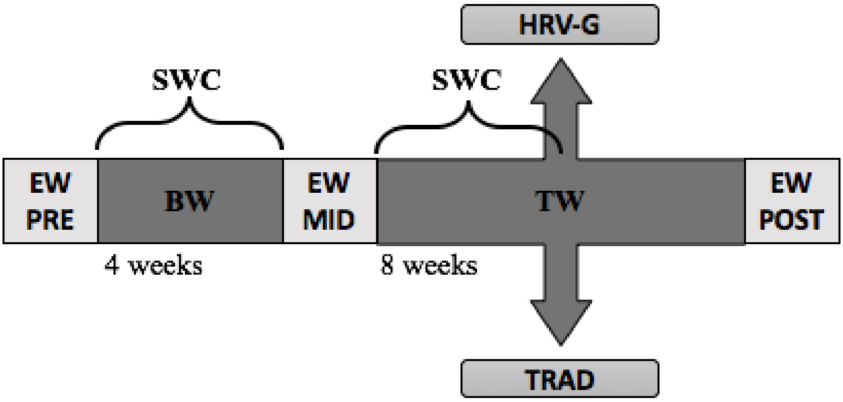


Figure 4. Experimental design. EW: Evaluation weeks; BW: Baseline weeks; TW: Training weeks; HRV-G: HRV-guided training group; TRAD: Traditional training group.

Procedures

HRV vs TRAD Training

Participants maintained their weekly training volume during BW and TW. During EW, participants were encouraged to not perform any vigorous training session and to rest 24 h prior to each test. During BW, the training intensity was increased gradually during the three first weeks and then reduced for the last week: 3 weeks of overload training and 1 recovery week (3:1). BW served as a preparatory period for familiarization with training sessions and their intensities. Nevertheless, all participants were accustomed to high-intensity training prior to the beginning of the study. Training sessions and periodization of TRAD group are displayed in Table 3, including low training sessions (Low; Intensity <VT1), moderate (Mod; VT1-VT2), High Intensity training (High; ≥VT2) and High Intensity Interval Training (HIIT; >VT2).

For HRV-G, training in TW was prescribed according to their CAR status[66,68] following a decision-making schema modified from Kiviniemi et al. (Figure 5).[66] Cyclists only performed two consecutive sessions of moderate or high-intensity training and did not accumulate more than two consecutive days of rest. The HRV baseline was calculate as the smallest worthwhile change (SWC), explained below (HRV measurements). When $LnRMSSD_{7day\text{-}roll\text{-}avg}$ fell outside the SWC, training intensity changed from moderate or high intensity training to low intensity training or rest. Typical training sessions are displayed in Table 3, moderate and high intensity training sessions were performed with a 45-60 min warm up and 20 min of cooling down. Figure 6 is an example of HRV fluctuations during the TW period.

There were three evaluation weeks (EW): PRE (Before BW), MID (Between BW and TW) and POST (After TW). Each week of evaluation, consisted of two testing sessions with a 48 h recovery period. The first testing session included a maximal graded exercise test to obtain maximal oxygen uptake (VO_2max) and both ventilatory thresholds (VT1 and VT2) and their derived power outputs. In the second one, participants performed a 40-min simulated time trial.

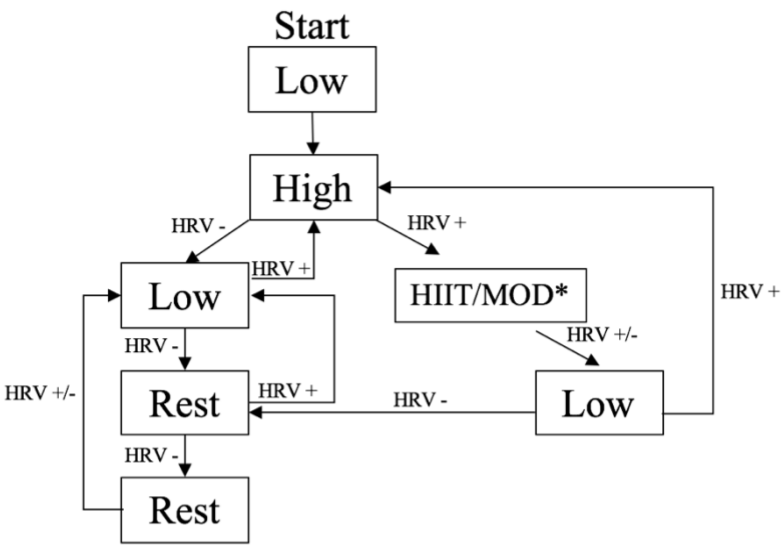


Figure 5. HRV-guided training schema. Modified from Kiviniemi et al.[66] When $LnRMSSD_{7day\text{-}roll\text{-}avg}$ remained inside SWC (+), high intensity or moderate training sessions were prescribed. If $LnRMSSD_{7day\text{-}roll\text{-}avg}$ fell outside SWC (-), low intensity or rest were prescribed.

**HIIT/MOD sessions were alternated each week.*

Graded Exercise Test

VO_2max, VT1 and VT2 were calculated with a maximal graded exercise test (GXT). The test started with a 10 min warm-up at 50 W, followed by an increase of 25 $W\cdot min^{-1}$ until exhaustion.[72] Participants performed all the test on their own bike, which was fitted on a Wahoo Kickr Power Trainer (Wahoo Fitness, Atlanta, GA).[71] The Wahoo Kickr Power Trainer was calibrated in each test during the 10-min warm-up according to the manufacturer's recommendation. Participants were allowed to cycle at their own preferred cadence. The graded exercise test was terminated when a cyclist's cadence dropped more than 10 rounds per minute (rpm) below their preferred cadence for more than 10 seconds. During the test, strong verbal encouragement was given in an attempt to make sure that the cyclist performed to his maximal capacity.
Maximal oxygen consumption or VO_2max was calculated as the highest 30 second VO_2 average. For the determination of VT1 and VT2, 15-s O_2 and CO_2 averages were used.[73] Respiratory gas exchange was measured MasterScreen CPX (Jaeger Leibniztrasse 7, 97204 Hoechberg, Germany) on a breath-by-breath basis and after the device was calibrated.
Peak power output (PPO), Power at VT1 (WVT1) and Power output at VT2 (WVT2) were also calculated derived from this test.

Simulated 40-min Time-Trial

To measure endurance performance, cyclists performed a 40-min all-out time-trial (40TT) in the laboratory. Prior to the start of 40TT, a 10-min warm-up was performed at a constant work of 50 W. Calibration of the GXT was done as part of the warm-up. Cyclists were able to pace themselves throughout the test and change their gear ratio and pedal frequency as they preferred. Environmental condition, such as temperature and humidity, were kept standard during all tests. Strong verbal encouragement during the 40TT was given by researchers, while all data was blinded from the cyclists except for time. Cyclists were allowed to drink water *ad libitum* through the test. Performance and endurance capacity was determined by the mean power output during the 40TT.

HRV measurements

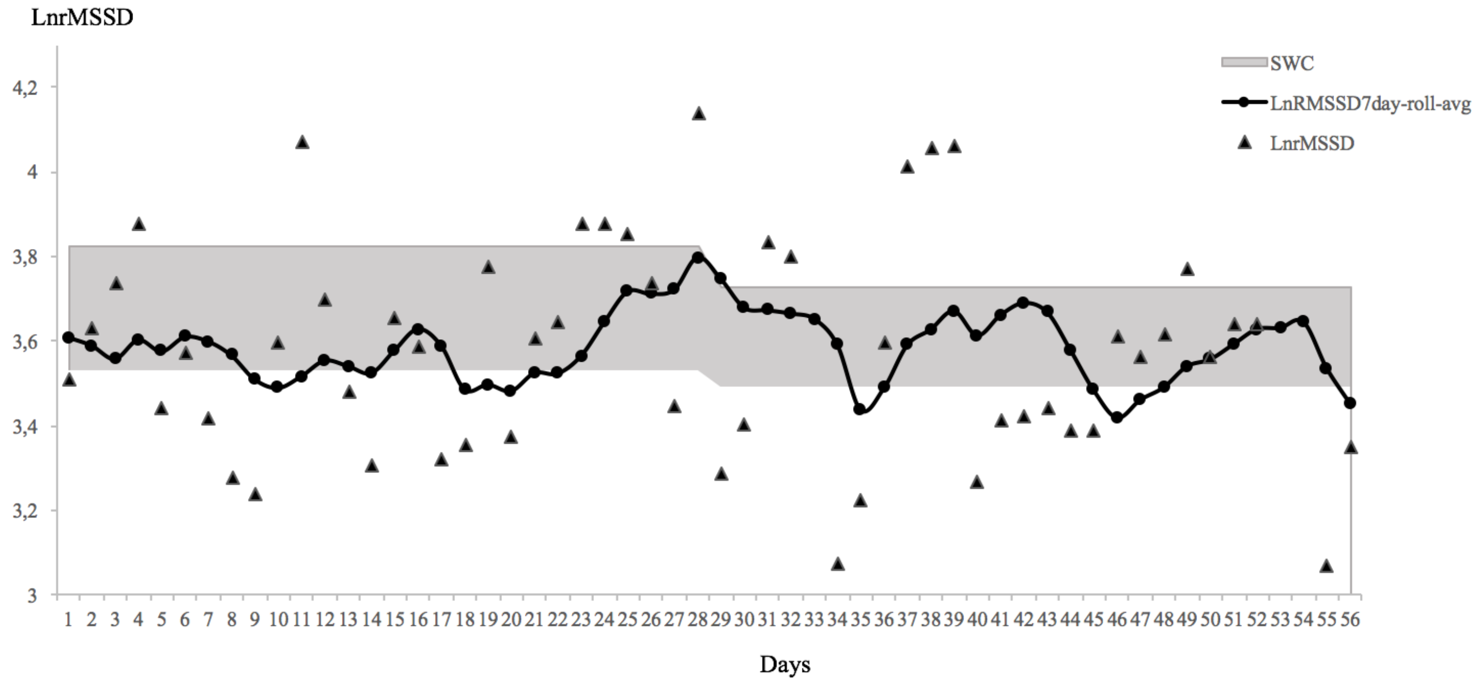
All participants were instructed to measure their RR interval data at home every morning after waking up and emptying their urinary bladder, both during BW and TW period. The HRV measurement were captured with a Polar H7 strap (Polar Team System, Polar Electro Oy, Kempele, Finland) and sent via app cloud service (Elite HRV app)[91] for analysis. HRV was measured in a supine position and over a 90 s period.[59] Cyclists were instructed to lie still and not to perform any further activity during recordings. The HRV data were analyzed by Kubios HRV software (Finland Eastern University, Kuopio, Finland).[92] The first thirty seconds of the HRV measurement were discarded,[74] while a middle-level filter of artifact correction was applied on the rest of the data. The root mean squared differences of successive RR intervals (RMSSD) was chosen as the vagal index, based on its greater suitability and reliability than other indexes.[57,65] The HRV data was transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution. A 7-day rolling average ($LnRMSSD_{7day\text{-}roll\text{-}avg}$) was calculated for the purpose of training prescription.[54] During BW, the SWC of LnRMSSD was calculated as mean ± 0.5 x SD, following the recommendations of Plews et al.[54] and its usefulness for training prescription based on HRV measurements.[68] SWC was updated after the first 4 weeks of TW due to the relationship between CAR and the adaptation to training.[34] This SWC was used for the interpretation of changes in $LnRMSSD_{7day\text{-}roll\text{-}avg}$ and the consequent training prescription during the following 4 weeks.

Table 3. Periodization and training distribution for both groups during weeks 1-5 and for TRAD during weeks 7-14.

Weeks	Type	Test	High Intensity	HIIT	Moderate Intensity	Low Intensity
1	EW PRE	GXT and 40 min Time-Trial				
2	BW				40 min between VT1 and VT2	3-5 sessions between 120 and 180 min below VT1
3	BW			4x8 min >VT2 / 3' rec	40 min between VT1 and VT2	2-3 sessions between 120 and 180 min below VT1
4	BW		30 min at VT2	4x8 min >VT2 / 3' rec	40 min between VT1 and VT2	2-3 sessions between 120 and 180 min below VT1
5	BW					3-5 sessions between 120 and 180 min below VT1
6	EW MID	GXT and 40 min Time-Trial				
7	TW		30 min at VT2		40 min between VT1 and VT2	3-5 sessions between 120 and 180 min below VT1
8	TW			4x8 min >VT2 / 3' rec	40 min between VT1 and VT2	2-3 sessions between 120 and 180 min below VT1
9	TW		30 min at VT2	4x8 min >VT2 / 3' rec	40 min between VT1 and VT2	2-3 sessions between 120 and 180 min below VT1
10	TW					3-5 sessions between 120 and 180 min below VT1
11	TW		30 min at VT2		40 min between VT1 and VT2	3-5 sessions between 120 and 180 min below VT1
12	TW			4x8 min >VT2 / 3' rec	40 min between VT1 and VT2	2-3 sessions between 120 and 180 min below VT1
13	TW		30 min at VT2	4x8 min >VT2 / 3' rec	40 min between VT1 and VT2	2-3 sessions between 120 and 180 min below VT1
14	TW					3-5 sessions between 120 and 180 min below VT1
15	EW POST	GXT and 40 min Time-Trial				

High Intensity, HIIT and Moderate session were performed with a 45-60 min warm up and 20 min of cooling down
EW: Evaluation week
BW: Baseline week
TW: Training week
GXT: Graded exercise test
VT1: First ventilatory threshold
VT2: Second ventilatory threshold

Figure 6. Example of individual response of HRV in a HRV-G cyclist.



SWC: Smallest worthwhile change
LnRMSSD: The natural logarithm of the root mean squared differences of successive RR intervals
LnRMSSD$_{7day\text{-}roll\text{-}avg}$: 7-day rolling average of the natural logarithm of the root mean squared differences of successive RR intervals

Statistical Analysis

The homogeneity of the data was tested with a Levene's test, to assure that all data was normally distributed. Based on the normal distribution the data are presented as mean ± standard deviation. A repeated measure of ANOVA followed by a Bonferroni post hoc test was performed to detect both, within- and between-group changes in TW and to assess possible changes in all participants during BW. In addition, data were analysed for practical significance using magnitude-based inferences both within- and between-groups comparison.[75] The smallest worthwhile difference in means in standardized (Cohen's *d*) units was set at 0.2, representing the hypothetical smallest difference within- and between-groups. Furthermore, chances that any change was greater/similar/smaller than the other group was calculated [using effect size and its 90% confidence limits (CL)]. Qualitative assessment of the magnitude of change was included according to the chances of benefit: most unlikely (<0.5%); very unlikely (0.5 to 5%); unlikely (5 to 25%); possibly (25 to 75%); likely (75 to 95%); very likely (95 to 99.5%); most likely (>99.5%).[75] If the 90% CL overlapped small positive or negative values, the magnitude of change was labelled unclear. Results were analysed with IBM SPSS Statics v.24 (SPSS Inc., IL, USA) for the repeated measure of ANOVA and Microsoft Excel 2016 (Microsoft Corporation, WA, USA) for the magnitude-based inference analysis.

Results

Training

In BW, HRV-G and TRAD followed the same training prescription (3:1). There were no statistical differences in volume nor intensity distribution in either group during this period. The amount of time/week for both groups were 8 h 17 m ± 2 h 48 min for HRV-G and 8 h 13 m ± 2 h 42 min for TRAD. Furthermore, the percentages of time in the different intensity zones (below VT1/ between VT1 and VT2/ above VT2) were 61/29/10 % and 60/31/9 % for the HRV-G and TRAD group respectively. During this period PPO ($p = 0.003$) and 40TT ($p < 0.0001$) improved while VO2max, WVT2 and WVT1 showed no changes.

In TW, the amount of time/week for both groups were 9 h 18 m ± 2 h 50 m for HRV-G and 8 h 46 m ± 2 h 47 m for TRAD. In addition, the percentages of time in the different intensity zones (below VT1/ between VT1 and VT2/ above VT2) were 66/24/10% and 64/27/9% for the HRV-G and TRAD group respectively. Percentage of time between VT1 and VT2 was significantly higher in TRAD [p = 0.04; *d* = 0.29 (-0.05 ; 0.53)] than in HRV-G. Percentage of time expended below VT1 [p = 0.21; *d* = 0.14 (-0.20 ; 0.47)] and above VT2 [p = 0.13; *d* = 0.13 (-0.14; 0.53)] did not differ between groups.

Within-group

In TW, within-group differences and practical significance are presented in Table 4. HRV-G improved PPO (5.1 ± 4.5 %; p = 0.024), WVT2 (13.9 ± 8.8 %; p = 0.004) and 40TT (7.3 ± 4.5 %; p = 0.005). VO_2max and WVT1 remained similar, with no significant changes. Figure 7 represents individual changes in endurance performance (40TT) for both groups. Only one participant in HRV-G decreased the power output during 40TT in POST (-1%) while in TRAD two subjects decrease the power output during 40TT by -2% and -5%. In addition, HRV-G presents the best individual increments in performance.

Between-group

For all the variables measured during EW (VO_2max, PPO, WVT1, WVT2 and 40TT) there were no differences between-groups in PRE, MID and POST. Between-group practical significance and qualitative assessment are displayed in figure 8. This comparison showed that HRV-G produced greater increases in PPO, WVT2 and 40TT.

In addition, there were significant differences (p = 0.0006) in the relative change of LnrMSSD between groups (Figure 9). There was lower variation for HRV-G group (0.85 ± 3.21%) than TRAD (-2.02 ± 5.21%).

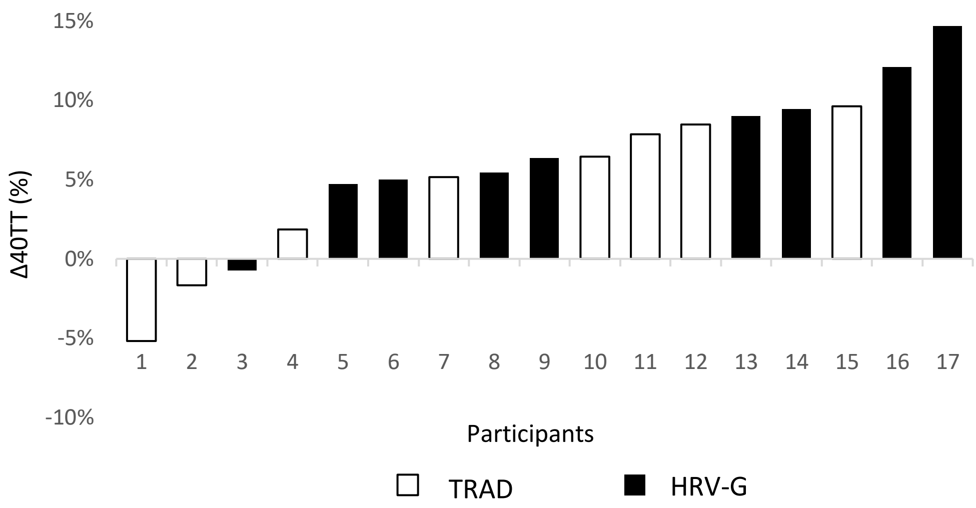


Figure 7. Individual differences in changes in performance for both groups.

40TT: Power output during the 40-min time-trial

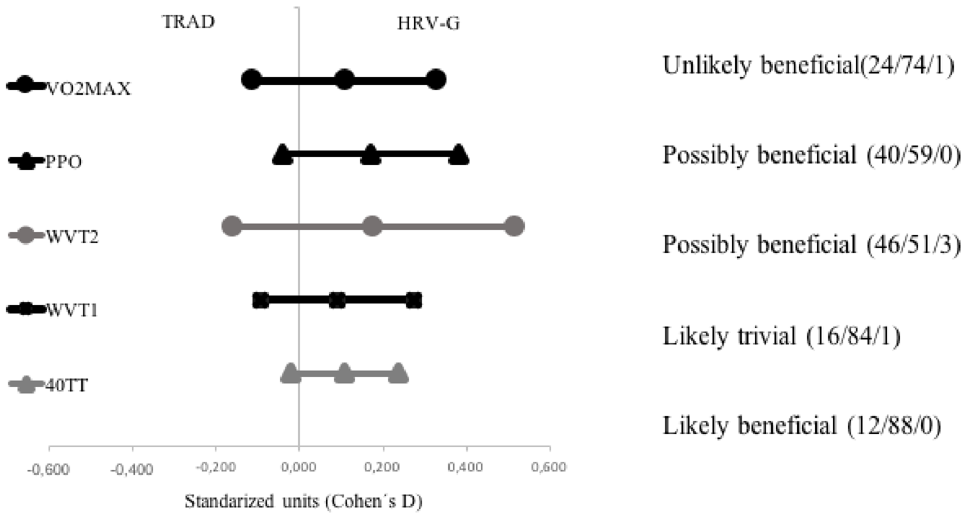


Figure 8. Between-group changes in performance.

PPO: Peak power output
WVT2: Power output at VT2 intensity
WVT1: Power output at VT1 intensity
40TT: Power output during the 40-min time-trial

Table 4. Within-group differences in the main variables measured.

	HRV-G (n = 9)					TRAD (n = 8)				
Variables	MID	POST	Standardised change (90% confident limits)	Chances	Qualitative assessment	MID	POST	Standardised change (90% confident limits)	Chances	Qualitative assessment
VO2max	56,34 ± 7.58	55,8 ± 8.18	-0.09 (0.41; -0.58)	16/51/34	unlikely beneficial	54.30 ± 7.81	52.13 ± 6.78	-0.22 (0.15; -0.59)	3/42/55	very unlikely beneficial
PPO	356.83 ± 39.74	374,28* ± 43.65	0.38 (0.58; 0.17)	92/8/0	likely beneficial	346,75 ± 16.73	351.50 ± 17.01	0.25 (1.11; -0.61)	54/28/18	unclear
WVT2	275.00 ± 41.46	311,11** ± 37.73	0.94 (1.30; 0.59)	100/0/0	most likely beneficial	256.25 ± 17.68	281.25 ± 22.16	1.02 (1.77; 0.27)	96/3/1	very likely beneficial
WVT1	191.67 ± 27.95	200.00 ± 25.01	0.32 (0.62; 0.01)	75/24/1	possibly beneficial	175.00 ± 23.15	178.13 ± 28.15	0.07 (0.42; -0.29)	29/64/7	unclear
40TT	243.11 ± 41.73	260,78** ± 44.76	0.33 (0.45; 0.21)	96/4/0	very likely beneficial	214.42 ± 32.36	223.13 ± 36.15	0.21 (0.40; 0.03)	53/47/0	possibly beneficial

*p < 0.05; ** p < 0.01
PPO: Peak power output
WVT2: Power output at VT2 intensity
WVT1: Power output at VT1 intensity
40TT: Power output during the 40-min time-trial

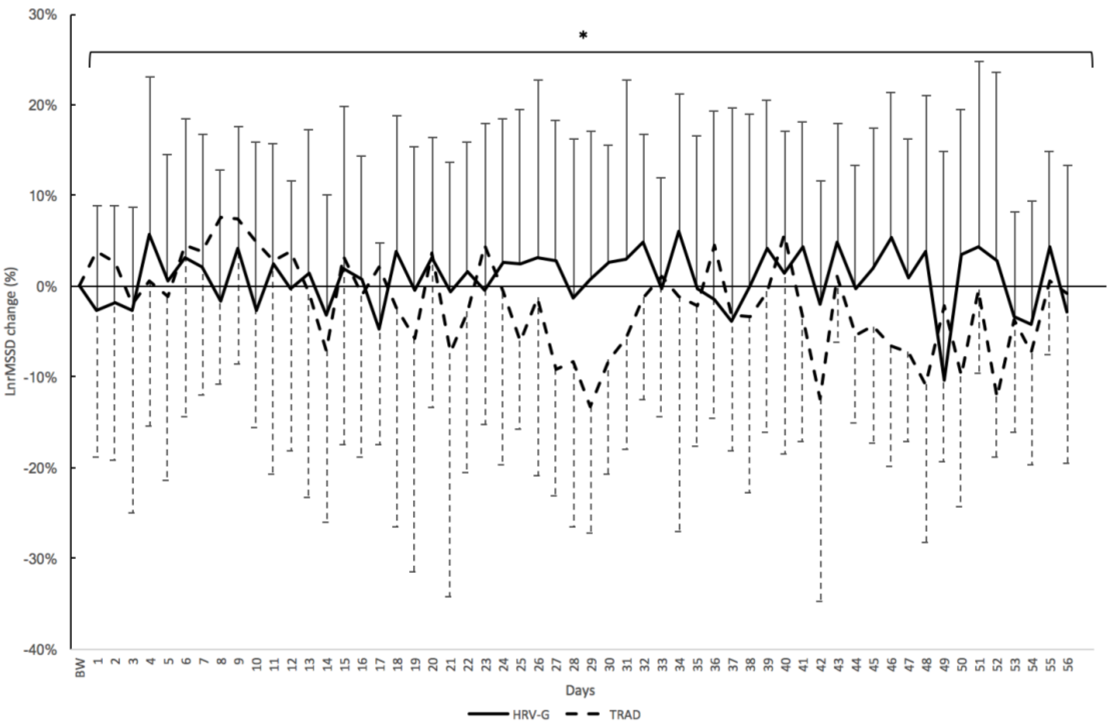


Figure 9. LnRMSSD change (%) during TW period for both, the HRV-G and TRAD groups.

** p < 0.001 for difference of change in LnRMSSD between groups.*
BW: Baseline weeks
TW: Training weeks
HRV-G: Heart rate variability training group
TRAD: Traditional training group

Discussion

This study set out with the aim of comparing the effect of a day-to-day training prescription based on HRV and a traditional training programme. The major finding was that HRV-G led to substantial greater increase in PPO, WVT2 and 40TT than TRAD shown by a possibly beneficial effect for PPO and WVT2 and a likely beneficial effect for 40TT (Figure 8). Furthermore, power output in the main variables showed greater magnitude of change in HRV-G, suggesting positive effects for this group. To the best of our knowledge, this is the first study to apply a training program based on HRV in road cycling.

The time expended between VT1 and VT2 was lower in HRV-G than in TRAD. Consequently, the percentage of time below VT1 was higher (but not significantly) in HRV-G while time expended upper VT2 remained similar between groups. The distribution in HRV-G is in accordance with the report by Da Silva et al.[69] which found a lower proportion of moderate intensity for the HRV guided training group. Regarding these differences, training prescription based on resting morning values of HRV could lead to a lower proportion of moderate and a greater low and high intensity training. This distribution has demonstrated greater performance enhancement in well-trained and elite endurance athletes.[93] Thus, the decision-making schema (Figure 5) and the SWC (Figure 6) could provide a distribution of training sessions that favors performance improvement. VO_2max is considered one of the factors that determine performance in endurance sports.[12] VO_2max did not change in either group and presents unlikely beneficial effects. The results differ from some studies reporting beneficial changes in VO_2max for the HRV-G.[66,68] However, these studies were performed with untrained[66] and recreational runners[67,68] and VO_2max is more susceptible to change due to the adaptation to training in this population. Thus, the differences in the results could be as a consequence of the participant's high-performance level because the trainability of this parameter is limited in well-trained and elite endurance athletes.[94]

PPO is a parameter that indicates the aerobic potential of cyclists.[95] In HRV-G, PPO increased significantly and presented possible beneficial effects. Furthermore, HRV-G presents a greater magnitude of change than TRAD (Table 4). These results are in accordance with other studies[35,66,67] which found similar increases in maximal aerobic velocity when applying the training guided by HRV in middle-distance running, like road cycling an endurance sport with similar demands. It has been suggested that high intensity training could improve PPO.[96] Although training intensity over anaerobic threshold was similar for both groups, PPO increased more in HRV-G. In HRV-G, only high intensity training was prescribed when the $LnRMSSD_{7day\text{-}roll\text{-}avg}$ values were within the SWC. Our hypothesis for this greater adaptation to training for HRV-G is in line with the idea of performing high intensity training when the athlete is in optimal conditions to perform it. Therefore, these differences in PPO changes may be due to a better timing in the programming of high intensity training.

The competitive situations that have a major impact on the result of a race are mountain passes and time-trials. Although the competition in road cycling is performed around the aerobic threshold in mass-start races,[78,79] the mountain passes are performed around anaerobic threshold.[97] Thus, WVT2 is one of the performance determinants in road cycling. WVT2 improved significantly in HRV-G but not in TRAD. However, the magnitude of change for both groups (Table 4) showed a most likely beneficial result for HRV-G and very likely beneficial result for TRAD. These results were in line with those reported by the literature,[66–68] showing greater effects for HRV-G (Figure 8). In addition, that the percentage of cyclists who improved WVT2 was 89% for HRV-G and 63% for TRAD. These results support the idea that the homogenization of the traditional training programs produces different levels of response and adaptation of the athletes, preventing the individualization and the adjustment of the training load, which would be obtained using the HRV as a tool to control adaptation.[35] Therefore, tools such as HRV will allow to take the principle of individualization of the load a step further.

Regarding WVT1, this parameter did not change significantly in either group and presents a trivial between-group effect (Figure 8). In addition, the results showed possibly beneficial effects for HRV-G and unclear effects for TRAD (Table 4). These results differ from other results[67] that reported significant increases for both, the group that performed training based on HRV and the predetermined training group. However the study by Nuuttila et al.[67] implemented resistance training in their methodology while our study only included endurance training. It has been previously reported that concurrent training of strength and endurance could lead to increases in aerobic capacity and performance.[10,98] This fact might explain the different outcome in this variable, leading to the absence of significant changes in our study. The qualitative assessment based on the effect size showed possible beneficial effects for the change in WVT1 for HRV-G whereas it showed unclear results for TRAD. In this case we cannot compare our result with those previously reported[67] because previous studies did not perform this analysis.

Performance, measured through 40TT, increased in HRV-G but not in TRAD (Table 4). In addition, HRV-G lead to substantial greater increase in this variable with higher magnitude of change. The finding mirrors those of the previous studies[68,69] that have examined the effect of a day-to-day training prescription based on HRV compared to a traditional training prescription. In this case, power output during 40TT was between WVT1 and WVT2 (Table 4), while the percentage of time expended at moderate intensity (between VT1 and VT2) was significantly lower the in HRV-G group. Therefore, the greater improvements in HRV-G may be due to a better periodization of the different type of training sessions. Another explanation for this result could be that the greater improvement in PPO and WVT2 also caused the improvement in performance in 40TT due to the increase of aerobic performance.

Daily variation of HRV was significantly greater for TRAD instead of HRV-G (Figure 9). In addition, the standard deviation was also greater for TRAD group. This result suggests that maintaining HRV values within an optimal range during the training process could result in greater increases in performance. This finding is in accordance with other study[90] performed in cross-country skiing, suggesting lower variations in daily HRV measurements and higher increases in performance for a HRV-guided training group.

This study has some limitations that must be highlighted: a) Training was performed by the cyclists without direct supervision during the training sessions. However, cyclists uploaded their data immediately after training sessions were performed and were supervised on a daily basis. Road cycling is a sport that is performed outdoors, so it is complex to perform the training sessions with the presence of the research group. b) HRV measurements were performed at home and without direct supervision. However, all data was revised every morning to detect possible mistakes in the measurements. Furthermore, participants were carefully instructed during PRE. This evaluation week also served as a familiarization period with all procedures. In addition, it's impractical for cyclists to come to the laboratory to evaluate HRV morning values every day during the study period. c) The determination of SWC was calculated with the same criterion for all the participants when HRV presented a high variation between subjects.[63] More research is necessary to develop new methodologies to establish an individualized SWC that could be more accurate than a fixed calculation of this range.

Practical applications

This study showed greater improvements for a day-to-day prescription than a predefined training program. To the best of our knowledge, a day-to-day training prescription based on daily HRV measurements had not been tested in this sport yet. In endurance sports with high physiological demands, like road cycling, the timing in the prescription of training load is a key factor to optimize the increases in performance. This study reflects how to optimize the training process based on the status of the cyclists and their response to the previous training sessions.

Furthermore, this study has been conducted with a smartphone application and a commercial Bluetooth strap to perform the measurements, highlighting the accessibility of the HRV measurements for field conditions. In addition, ultra-short HRV recordings have been used to evaluate fatigue and response to training but not in day-to-day training prescription. This study provides support for the possibilities of these recordings, which has great practical applications in the field. Previous studies of day-to-day training prescription used ≥ 4 min HRV recordings while in this study, the measurements were performed with ultrashort HRV recordings.

Conclusions

The greater improvements in HRV-G showed that prescribing moderate and high-intensity training according to CAR could be more effective than traditional training prescription based on a predetermined training load, during a relatively short period of time (8 weeks) in well-trained cyclists. Future research is required to implement this new trend in training load prescription for several reasons: First, to apply this method to other level cyclists such as professional cyclists, without much room for further development of aerobic capabilities and performance due to their level. Second, to expand knowledge towards new schemes to prescribe training sessions and an individualization of the SWC.

8. TRAINING PRESCRIPTION GUIDED BY HEART RATE VARIABILITY VS. BLOCK PERIODIZATION IN WELL-TRAINED CYCLISTS.

8. Training prescription guided by heart rate variability vs. Block periodization in well-trained cyclists.

Abstract

Predefined training programmes are common place when prescribing training. Within predefined training, block periodization (BP) has emerged as a popular methodology due to its benefits. Heart rate variability (HRV) has been proposed as an effective tool for prescribing training. The aim of this study is to examine the effect of HRV guided-training against BP in road cycling. Twenty well-trained cyclists participated in this study. After a preliminary baseline period to establish their resting HRV, cyclists were divided into two groups: an HRV-guided group and a BP group and they completed 8 training weeks. Cyclists completed three evaluations weeks, before and after each period. During the evaluation weeks, cyclists performed: (1) a graded exercise test to assess VO_2max, peak power output (PPO) and ventilatory thresholds with their corresponding power output (VT1, VT2, WVT1, and WVT2, respectively) and (2) a 40-min simulated time-trial (40TT). The HRV-guided group improved VO_2max ($p = 0.03$), PPO ($p = 0.01$), WVT2 ($p = 0.02$), WVT1 ($p = 0.01$) and 40TT ($p = 0.04$). BP group improved WVT2 ($p = 0.02$). Between-group fitness and performance were similar after the study. The HRV-guided training could lead to a better timing in training prescription than BP in road cycling.

Keywords: cardiac autonomic regulation; cycling; endurance training; day-to-day; aerobic performance.

Introduction

Prescribing training load to achieve optimal performance is generally based on a predetermined program which is worked back from the moment an athlete has to peak at important sports event. Within the different types of training approaches, block periodization (BP) has emerged as one of the most popular methods to structure a program.[3] BP consists of training cycles of well concentrated workloads.[1] and its effectiveness is supported by a large body of research.[1,3,5,6,9,11,99] The concentrated workloads within BP, are focused on limited target abilities, with the aim to maximize the development of the performance while avoiding excessive fatigue accumulation.[1,3]

The BP method is used in many sports ranging from kayaking to cycling. In kayaking[5,99] and cross-country skiing[6] , BP lead to larger improvements in fitness and performance than multi-targeted traditional training prescription. In road cycling, BP has shown to results in greater improvements in VO_2max, power output at 2 mmol/L and 40-min time trial performance.[9,11,100]

However, most the research around predefined training programmes show inter-individual variation with some subjects responding better than other or in some cases subjects not responding.[20,101] In the field, the monitoring of predefined training programs are generally done by measures of training load. However, changes in predefined training due to unexpected response of the athlete are based on subjective criteria of the coach and athlete. Although coaches play an extremely important role in monitoring athletes and know them really well, making decision purely based on subjective data is challenging.

With the growth of new methodologies and technologies in the past decade, the possibilities to objectively monitor athletes has substantially grown. This development also has created the opportunity to individualize and adapt training programs in order to prescribe the most effective training programs. One of the new promising tools to monitor and fine-tune training is heart rate variability (HRV). HRV has shown to be a valid and reliable tool to assess cardiac autonomic regulation,[42] which is able to reflect positive and negative adaptation to training programs.[35] and to reflect fatigue induced by training or other daily stressors.[34]

Due to the development of new methodologies (shorter recordings) and technologies (mobile apps) for collecting HRV (i.e. shorter recordings, simple analysis),[59,61,62] it is possible to measure HRV on a daily basis. HRV has been used to prescribe training in running,[66,68,89] cross-country skiing,[102] and road cycling.[103] It has been shown that HRV-guided training elicited similar increments in fitness and running performance in recreational runners with no differences in the amount of training nor in the training intensity.[67] In cyclists, Javaloyes et al.[103] showed greater increments in performance in well-trained cyclists trained based on HRV-guided training programme compared to a standardized program without HRV. Nuuttila et al.[67] reported similar benefits in performance when using either a HRV-guided or BP-guided training program in recreational runners.

However, to our knowledge no study to date has compared the use of an HRV guided and BP-guided training program in cyclists. As such, the purpose of this study was to determine the effect of a HRV-guided and BP-guided training program on road cycling performance in well-trained cyclists.

Methods

Experimental approach to the problem

The study protocol was divided into two periods; i) a baseline period (BW) and ii) a training period (TW). The BW lasted 2 weeks that were used as a standardization period after which a baseline HRV measurement could be developed. After the BW, cyclists were matched into pairs according their endurance characteristics (VO_2max and performance) and assigned to a HRV-guided training group (HRV-G, n=8) or a block periodization training group (BP, n=7). During the following 8 weeks, the cyclists trained based on the group they were allocated to. Cyclists in the HRV-G group trained according to their HRV morning values, while BP cyclists trained based on a predetermined training programme. There were three evaluation weeks (EW): PRE (before BW), MID (between BW and TW) and POST (after TW). Each EW consisted of two testing sessions with a 48-h recovery period. The first testing session included a maximal graded exercise and a 40-min simulated time trial.

Subjects

Twenty well-trained cyclists with at least a 2-year personalised training history were recruited for this study. The general characteristics of the subjects that were included for analyses, are shown in 54. Before taking part in the study, all subjects were fully informed about the study requirements and signed a written informed consent. The study was approved by the ethical committee of the Miguel Hernandez University and was conducted conforming to the recommendations of the Declaration of Helsinki.

Table 5. Participant characteristics.

	BP (n = 8)	HRV-G (n = 7)
Years	30.75 ± 10.48	28.14 ± 13.18
Training experience (years)	11.40 ± 3.06	11.32 ± 2.98
Height (m)	1.78 ± 0.05	1.74 ± 0.05
Weight (kg)	72.59 ± 10.37	73.76 ± 4.61
VO_2max	58.96 ± 6.23	58.94 ± 5.62

Procedures

Graded Exercise Test

VO_2max, first ventilatory threshold (VT1) and second ventilatory thresholds (VT2) were calculated with a maximal graded exercise test (GXT). The test started with a 10 min warm-up at 50 W, followed by a 25 $W \cdot min^{-1}$ increase until exhaustion.[72] Subjects performed all the test on their own bike, which was fitted on a Wahoo Kickr Power Trainer.[71] The Wahoo Kickr Power Trainer was calibrated in each test during the 10-min warm-up according to the manufacturer's recommendation. Subjects were allowed to cycle at their own preferred cadence. The graded exercise test terminated when a cyclist's cadence dropped more than 10 rounds per minute (rpm) below their preferred cadence for more than 10 seconds. During the test, strong verbal encouragement was given in an attempt to make sure that the cyclist performed to his maximal capacity.

Maximal oxygen consumption or VO_2max was calculated as the highest 30 second VO_2 average.[73] For the determination of VT1 and VT2, the 15-s O_2 and CO_2 averages were used. Respiratory gas exchange was measured with the MasterScreen CPX (Jaeger Leibniztrasse 7, 97204 Hoechberg, Germany) on a breath-by-breath basis and after the device was calibrated. Peak power output (PPO), Power at VT1 (WVT1) and Power output at VT2 (WVT2) were also calculated derived from this test.

Simulated 40-min Time-Trial

Performance was assessed via a 40-min all-out time-trial (40TT) in the laboratory. Prior to the start of the 40TT, a 10-min warm-up was performed at a constant work of 50 W. Calibration of the GXT was done as part of the warm-up. Cyclists were able to pace themselves throughout the test and change their gear ratio and pedal frequency as they preferred. Environmental conditions, such as temperature and humidity, were kept standard during all tests. Verbal encouragement during the 40TT was given by researchers and all feedback during the testing was blinded from the cyclists with the exception of accumulated time. Cyclists were allowed to drink water *ad libitum* throughout the test. Performance and endurance capacity were determined by the mean power output during the 40TT.

HRV measurements

All subjects were instructed to measure their RR interval data upon waking up and emptying their urinary bladder, both during the BW and the TW period. The HRV measurements were captured with the HRV4training (see http://www.hrv4training.com) smartphone application.[61] HRV was measured in a supine position and over a 90 s period.[59] Cyclists were instructed to lie still and to not perform any further activity during the recordings and the last 60 s of the HRV measurement were captured.[60] The root mean squared differences of successive RR intervals (RMSSD) was chosen as the vagal index, based on its greater suitability and reliability than other indexes. The HRV data was transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution. A 7-day rolling average ($LnRMSSD_{7day\text{-}roll\text{-}avg}$) was calculated for the purpose of training prescription.[80] During the BW, the smallest worthwhile change of LnRMSSD was calculated as mean ± 0.5 x SD.[68] The smallest worthwhile change was updated after the first 4 weeks of TW due to the relationship between CAR and the adaptation to training.[34] This smallest worthwhile change was used for the interpretation of changes in $LnRMSSD_{7day\text{-}roll\text{-}avg}$ and the subsequent training prescription during the following 4 weeks.

HRV vs. BP Training

Subjects maintained their weekly training volume during the BW and TW. During the EW, subjects were encouraged to not perform any vigorous training session and to rest 24 hours prior to each test. BW served as a preparatory period for familiarization with the training sessions and their intensities. Nevertheless, all subjects were accustomed to high-intensity training prior to the beginning of the study. The training sessions and periodization of the BP group are shown in Figure 10, including low training sessions (Low; Intensity <VT1), High Intensity training (≥VT2) and High Intensity Interval Training (HIIT; >VT2). The training blocks consists of 3 blocks of high intensity training (4 high intensity training sessions and HIITs per week followed by a block of low intensity training (4 low intensity training sessions and one HIIT session).

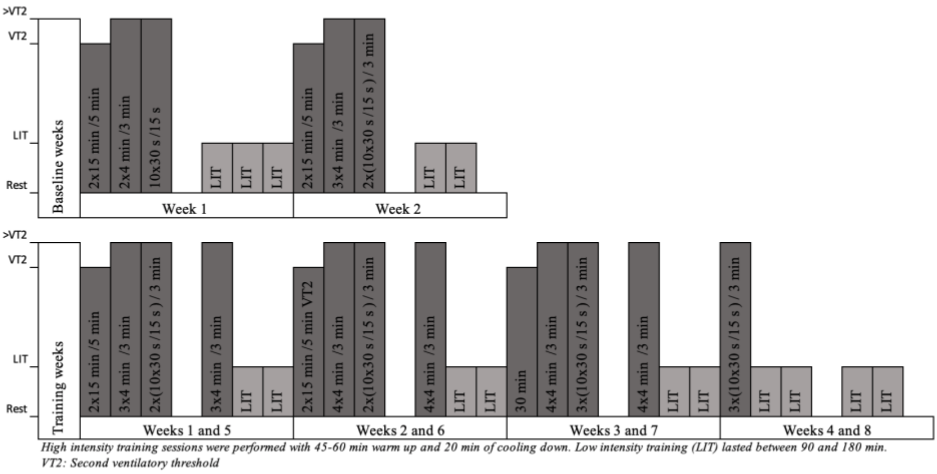


Figure 10. Description of the training program during baseline weeks and for block periodization group during training weeks

For the HRV-G group, training in TW was prescribed according to their HRV morning values following a decision-making schema [66] (figure 11). Cyclists only performed two consecutive sessions of high-intensity training and did not accumulate more than two consecutive days of rest. The HRV baseline was calculated as the smallest worthwhile change, explained below (HRV measurements). When $LnRMSSD_{7day\text{-}roll\text{-}avg}$ fell outside the smallest worthwhile change, training intensity changed from high intensity training to low intensity training or rest. Typical training sessions are displayed in Figure 10, high intensity training sessions were performed with a 45-60 min warm up and 20 min of cooling down period.

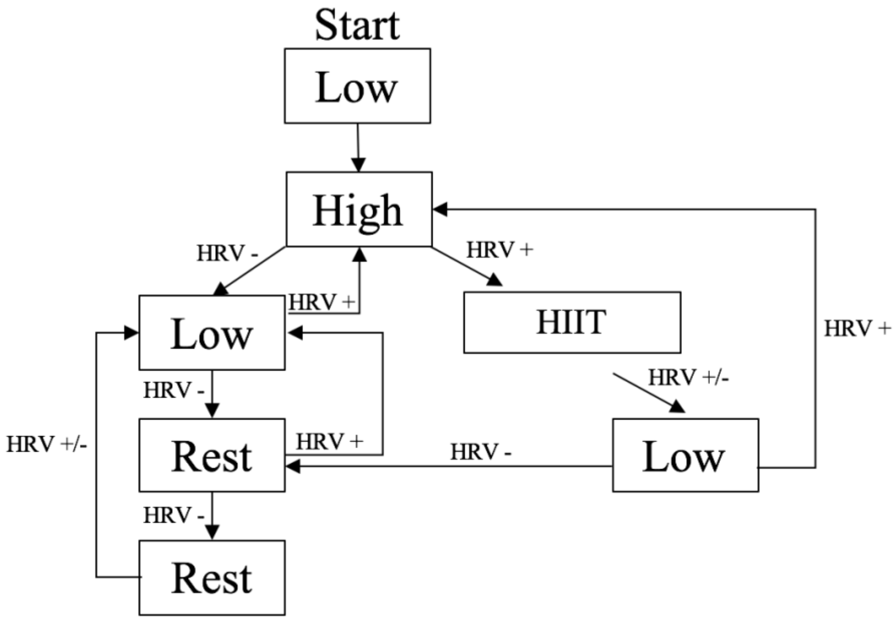


Figure 11. HRV-guided training decision making schema

Training load was calculated [in arbitrary units (AU)] with a training impulse formula[80] that takes volume (time) and intensity into account: TRIMP (AU) = [Time (s) below VT1 x 1] + [Time (s) between VT2 and VT2 x 2] + [Time (s) above VT2]. Training sessions were daily monitored by specific training software (TrainingPeaks, Boulder, United States)

Statistical Analysis

The homogeneity of the data was tested with a Levene's test, to assure that all data was normally distributed. Based on the normal distribution the data are presented as mean ± standard deviation. A repeated measure of ANOVA followed by a Bonferroni post hoc test was performed to detect both, within- and between-group changes in the TW and to assess possible changes in all subjects during the BW. In addition, data were analysed for practical significance using magnitude-based inferences both within- and between-groups comparison.[75] The smallest worthwhile difference in means in standardized units (Cohen's *d*) was set at 0.2, representing the hypothetical smallest difference within- and between-groups. Furthermore, chances that any change was greater/similar/smaller than the other group was calculated [using effect size and its 90% confidence limits (CL)]. The qualitative assessment of the magnitude of change was as follows: most unlikely (<0.5%); very unlikely (0.5 to 5%); unlikely (5 to 25%); possible (25 to 75%); likely (75 to 95%); very likely (95 to 99.5%); most likely (>99.5%).[75] If the 90% CL overlapped small positive or negative values, the magnitude of change was labelled unclear. Results were analysed with IBM SPSS Statics v.24 (SPSS Inc., IL, USA) for the repeated measure of ANOVA and Microsoft Excel 2016 (Microsoft Corporation, WA, USA) for the magnitude-based inference analysis calculated by specific spreadsheet "compare to groups means" (www.sportsci.org).

Results

A total of 15 cyclists completed the study. Five subjects dropped out due to injuries (n=1) and insufficient compliance (< 90%) with the training programme or the HRV measurements (n=4).

In the BW, there were no statistical differences in volume nor intensity distribution in either group during this period following the same training prescription (3:1). In the TW, the weekly volume for both groups was 11 h 06 m ± 3 h 04 m for HRV-G and 11 h 22 m ± 3 h 07 m for BP [p = 0.88; d = 0.06 (-0.78; 0.90); unclear]. In addition, the percentages of time in the different intensity zones (below VT_1/ between VT_1 and VT_2/ above VT_2) were 49/39/12% and 54/33/13% for the HRV-G and the BP group respectively. The between-groups difference in percentage of time expended below VT1 [p = 0.62; *d* = -0.26 (-1.35; 0.83); unclear], between VT_1 and VT_2 [p = 0.30; *d* = 0.56 (-0.55; 1.67); unclear] and above VT2 [p = 0.77; *d* = -0.15 (-1.24; 0.94); unclear] did not differ between groups. Between groups training load (AU) weekly average did not differ: 1033.28 ± 312.51 AU and 1028.81 ± 214.48 AU [p = 0.98; d = 0.03 (-0.77; 0.75); unclear] for HRV-G and BP, respectively.

In the TW, within-group differences and practical significance are presented in Table 2 while standardized change is showed in figure 12. The HRV-G group improved VO_2max (3 ± 3 %; $p = 0.03$; likely beneficial), PPO (7 ± 5 %; $p = 0.01$; very likely beneficial), WVT2 (17 ± 15 %; $p = 0.02$; very likely beneficial), WVT1 (26 ± 18 %; $p = 0.01$; very likely beneficial) and 40TT (6 ± 6 %; $p = 0.04$; likely beneficial). In contrast to HRV-G, BP-G only improved WVT2 (12 ± 12 %; $p = 0.02$; very likely beneficial), while VO_2max, PPO, WVT1 and 40TT remained unchanged.

Table 6. Within-group differences and practical significance in TW

	BP (n = 8)				HRV-G (n = 7)			
	MID	POST	Chances	Qualitative assessment	MID	POST	Chances	Qualitative assessment
VO2max	58.96 ± 6.23	62.65 ± 6.65	88/11/1	likely beneficial	58.94 ± 5.62	61.04 ± 6.01*	82/18/0	likely beneficial
PPO	388 ± 42	407 ± 51	65/24/11	possibly beneficial	395 ± 39	423 ± 28**	54/28/18	very likely beneficial
WVT2	280 ± 27	323 ± 52*	97/2/1	very likely beneficial	288 ± 52	349 ± 30*	97/2/1	very likely beneficial
WVT1	188 ± 29	190 ± 42	29/40/31	unclear	170 ± 37	234 ± 30*	99/1/0	very likely beneficial
40TT	262 ± 30	264 ± 33	24/64/12	possibly trivial	261 ± 28	280 ± 39*	91/8/1	likely beneficial

*$p < 0.05$; ** $p < 0.01$

PPO: Peak power output

WVT2: Power output at VT2 intensity

WVT1: Power output at VT1 intensity

40TT: Power output during the 40-min time-trial

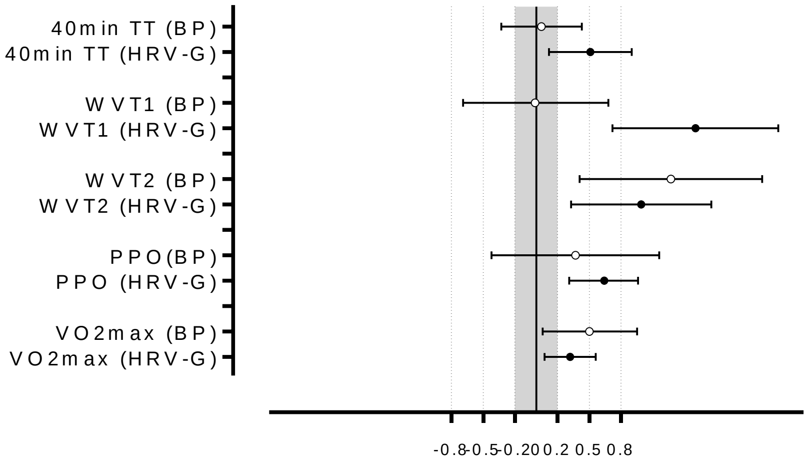


Figure 12. Standardized change for both groups (Cohen's D)
PPO: Peak power output
WVT2: Power output at VT2 intensity
WVT1: Power output at VT1 intensity
40TT: Power output during the 40-min time-trial

Individual changes in endurance performance (40TT) showed that only one participant in the HRV-G group decreased his performance (-0.5%) while in the BP group, three subjects reported lower power output during 40TT by -11.6%, -9,1% and -2.7%. Furthermore, the greatest individual changes were for the HRV-G group (Figure 12).

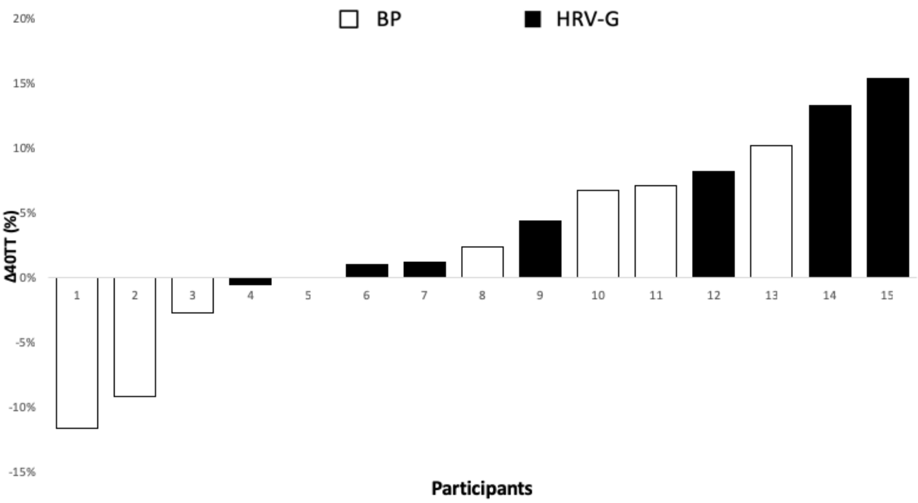


Figure 13. Individual changes in performance for both groups.

For all the variables measured during the EW (VO_2max, PPO, WVT1, WVT2 and 40TT) there were no differences between-groups in PRE, MID and POST. In addition, between-group practical significance and qualitative assessment during the TW showed unclear results, with the 90% CL overlapping small positive or negative values in VO_2max [*d* = 0.10 (-0.86; 0.87)], PPO [*d* = 0.15 (-0.72; 1.01)], WVT1 [*d* = -0.56 (-1.44; 0.31)], WVT2 [*d* = 0.17 (-0.72; 1.07)] and 40TT [*d* = -0.10 (-0.87; 0.86)].

Discussion

This study was to compare the day-to-day training prescription based on daily HRV measurements to traditional block periodization in well-trained road cyclists. Importantly, these data show that HRV guided training prescription presented a more positive response at improving fitness and performance than a block periodization. This was despite a comparable training volume, intensity distribution and training load. In addition, this study was carried out with new technology that facilitates daily monitoring of HRV.

Training volume was similar between groups as well as training intensity distribution. In addition, TRIMP remained similar between groups in TW. Similarly, other studies[67] have also reported identical intensity distribution and amount of training in an HRV-guided training group and a block periodization group in recreational runners. Accordingly, in this study, the amount of training (volume, training intensity, and TRIMP) cannot explain the observed improvements in fitness and performance for the HRV-G group compared to the BP. Previous research has reported a lower proportion of time in moderate intensity (between VT1 and VT2) when comparing HRV-guided training and a traditional periodization in both untrained[104] and well-trained athletes.[103] However, these studies are performed with multi-targeted training sessions, including low, moderate and high intensity training. The discrepancy could be attributed to training sessions that were focused on high intensity training targets (≥VT2) in this study.

A common denominator of high level endurance athletes is a high value of VO_2max.[12,94] In this study, the HRV-G group improved VO_2max (3 ± 3 %; $p = 0.03$). Qualitative assessment based on the standardized change reported likely beneficial effects for both groups (Table 2). This result matches those observed in earlier studies reporting increments in VO_2max for untrained,[104] recreationally[35,67] and elite[102] endurance athletes who followed an HRV-guided training. However, Javaloyes et al.,[103] also in well-trained cyclists, did not report increments in VO_2max for HRV-guided training. These observed differences may be due to cyclists completed a higher proportion of time at high intensities (≥VT2) in this study, obtaining greater increments in this variable. Regarding BP, our results are in line with those reported in cyclists of similar training status.[9,11] It can therefore be assumed that both periodization models led to improvements in VO_2max. This provides explanation around the unclear between-group results with using the MBI statistical method.

Peak power output in this study was obtained at VO_2max intensity which has been shown to be another strong determinant of aerobic performance of endurance athletes.[12,95] In this study, PPO only improved in the HRV-G group with no change in the BP group. In addition, the HRV-G group reported very likely beneficial effects with a 98% chance of benefit; in comparison, the BP group exhibited possible beneficial (65% chance of benefit, Table 2). These findings are in line with those reported previously[103] which found greater increments in this variable in well-trained cyclists. Whilst there were similar proportions of time expended > VT2 for both groups, one possible explanation for these differences could be that in HRV-G, cyclists only performed high intensity training when their $LnRMSSD_{7day\text{-}roll\text{-}avg}$ daily value remained inside smallest worthwhile change limits. This allowed training at high intensities to only be carried out in optimal recovery conditions, favoring positive adaptations.

WVT2 was another key variable assessed in this study. In road cycling, a large proportion of the event (E.g. time trials and mass-start road races) is performed around this intensity. In this study, WVT2 likely improved in both groups (figure 12). It has been previously reported that both, a day-to-day training prescription based on HRV measurements and a traditional periodization lead to increments in this parameters in well-trained cyclists.[103]

WVT1 increased in the HRV-G but not in the BP group. Furthermore, magnitude-based inference reported larger improvement in the HRV-G group than in the BP group in this variable with very likely beneficial and unclear assessment for the HRV-G and the BP groups, respectively (figure 12). Both groups expended similar amounts of time at this intensity. Although the differences were not statistically relevant, it is possible that the differences in moderate intensity (33% vs. 39 % for the BP and the HRV-G groups, respectively) may explain part of the large increments for HRV-G.

Performance (40TT) increased in the HRV-G but not in the BP group. Furthermore, qualitative assessment showed likely beneficial effects for the HRV-G while in the BP group reported possibly trivial effects. In a recent study,[103] HRV-G showed similar improvements in performance. The results obtained in the BP group differ from other results[11] that reported improvements in performance in well-trained cyclists. A possible explanation for this is that in the mentioned study was carried out during a 12-week period while the TW lasted 8 weeks. Thus, a longer duration could produce greater improvements in performance with block periodization in well-trained subjects. For this reason, it seems that the length needed to achieve meaningful increases in performance with a training prescription guided by HRV, could be shorter than BP because greater training quality. Individual changes in 40TT reported only one subject with a decrease in performance for the HRV-G while BP group presented 3 subjects with less power output in POST (Figure 13). In addition, the mean change was 6 ± 6 % and it has been suggested that changes lower than 4.4% could be due to normal day-to-day variation.[105] As such, these well-trained cyclists have more probability to increased his performance in a 40-min all-out effort by following a day-to-day training based on HRV measurements.

Periodization theories and, consequently, predefined training programmes based on these theories, offer a rational explanation of the distribution of stress (training load imposed to the athlete) and recovery periods with the goal of a peak in performance in main competitions. However, most of the strategies undertaken by coaches are integrated based on beliefs and traditions with limited scientific support.[20] Block periodization consists of training cycles of well concentrated and specialized workloads.[3] Despite the beneficial effects reported by block periodization models, concentrated workloads without valid and reliable measures of fatigue could lead to an overreached state that limit training adaptation. In this study, HRV was used to determine the fatigue of cyclists. If HRV decreased below smallest worthwhile change (representing an excess of fatigue accumulation), high intensity training was ceased until HRV returned inside smallest worthwhile change. HRV-G showed greater magnitude of change than BP in fitness and performance with a similar training load but varying the training sessions distribution between groups. Therefore, it seems that individualizing high intensity training when the athlete is in a state of optimal fatigue could lead to an improved adaptative response to training.

Monitoring HRV on a daily basis may provide useful information on adaptation and fatigue in athletes. The validity observed in ultra-short recordings of time-domain indices[62] and the development of validated mobile applications[61,62] have allowed the daily monitoring of HRV. The recordings were performed with the mobile application HRV4training that used photoplethysmography technology of the smartphone cameras. This avoids having to use a heart rate strap. This application reported almost perfect correlation and trivial standardised differences when compared with ECG.[61] Thus, the combination of ultra-short measurements and easy-of-use applications could mean that athletes would be much more likely to comply with daily recordings.[106]

The practical application for coaches and athletes worthy of mention. First, the HRV measurements were taken with ultra-short recordings, this implies cyclists are more likely to perform daily measurements during a long period of time (10 weeks for this study). Second, these measurements were performed using photoplethysmography technology with a validated smartphone application (HRV4training). This makes the measurement more comfortable for the athletes than the former alternative methods such as heart rate straps and ECG. Third, this study has been performed in an ecological context, where the evaluations were performed in controlled laboratory conditions but training was performed outdoors. The data was collected daily using cloud service of the applications both for HRV measurements (HRV4training) and training process (TrainingPeaks™). This is an essential part in the cyclist's as training normally occurs without the direct supervision from coaches on a daily basis. Accordingly, this study clearly shows the possibilities and usefulness of day-to-day training using HRV measurements.

Practical applications

The evidence from this study give further supports to the notion that HRV is a valid and reliable tool to detect the daily recovery/fatigue and subsequently prescribed training in well-trained cyclists. Thus, the implementation of daily HRV measurements and effective methodologies to change the training prescription on a daily basis could lead to a better timing in prescription. Thereby giving greater insight into the programming puzzle and optimizing training regimes to enhance in fitness and performance. The optimization of training programmes using tools to understand individual response to training plays a key role in the successful in competition, especially in individual sports were physical condition is the main performance factor. Day-to-day training gives insights into the use of objective measurements of the response to training and therefore allows to adjust training on a daily basis with greater precision.

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Conflict of interest

The authors declare that they do not have any potential conflict of interest.

PART III

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11. APPENDICES

11. Appendices

11.1 Appendix I. Criteria followed for the analysis of the graded exercise tests

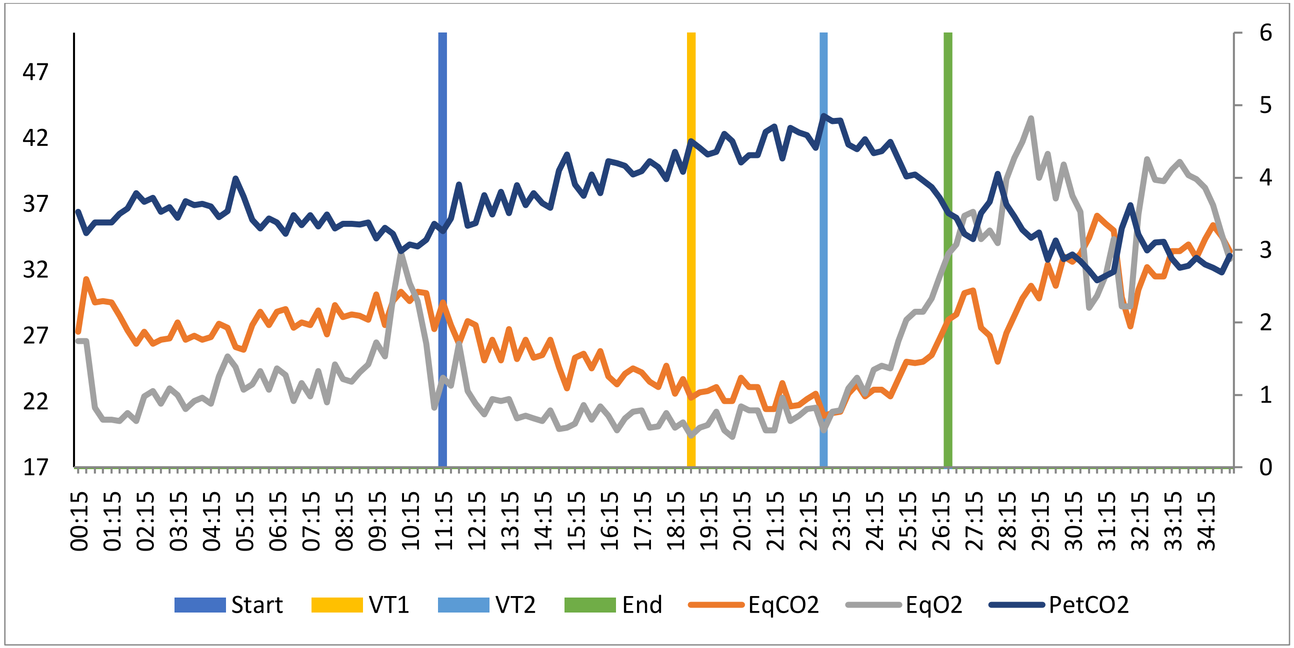

Figure 14. Detection of the first and second ventilatory threshold (VT1, VT2) using CO2 and O2 equivalents (EqCO2, EqO2) and Partial pressure of CO2 (PetCO2).

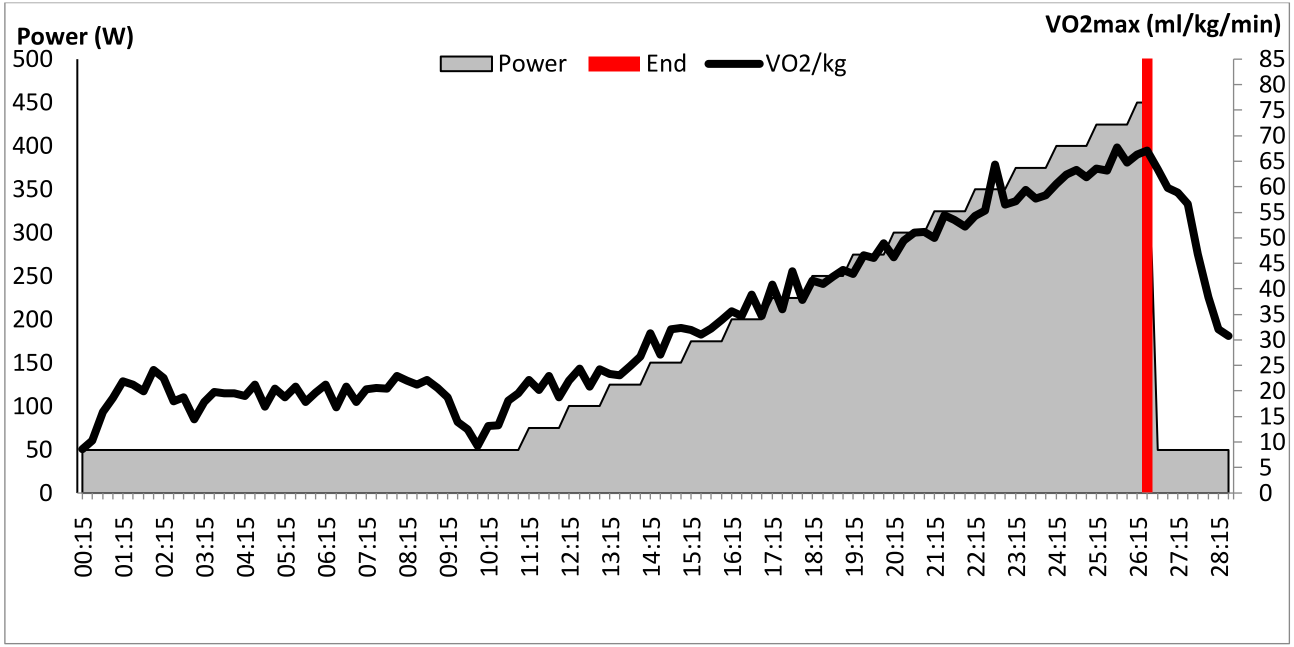

Figure 15. Detection of VO2max.

11.2 Appendix II. Technology to measure HRV

The purpose of this annex is to show some images regarding the use of the technology needed to perform daily measurements of HRV. As the technology used is different in both studies (chapter 7 and 8), this annex is divided into two parts or sections.

<u>Technology implemented in chapter 7:</u>

Step 1: Fitting the strap onto the chest.

Figure 16. Chest strap Polar H7 (Polar Team System, Polar Electro Oy, Kempele, Finland).

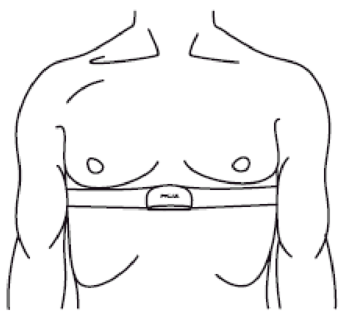

Figure 17. Correct position of the chest strap (according to the manufacturer's recommendation).

Step 2: Measuring HRV with Elite HRV mobile application

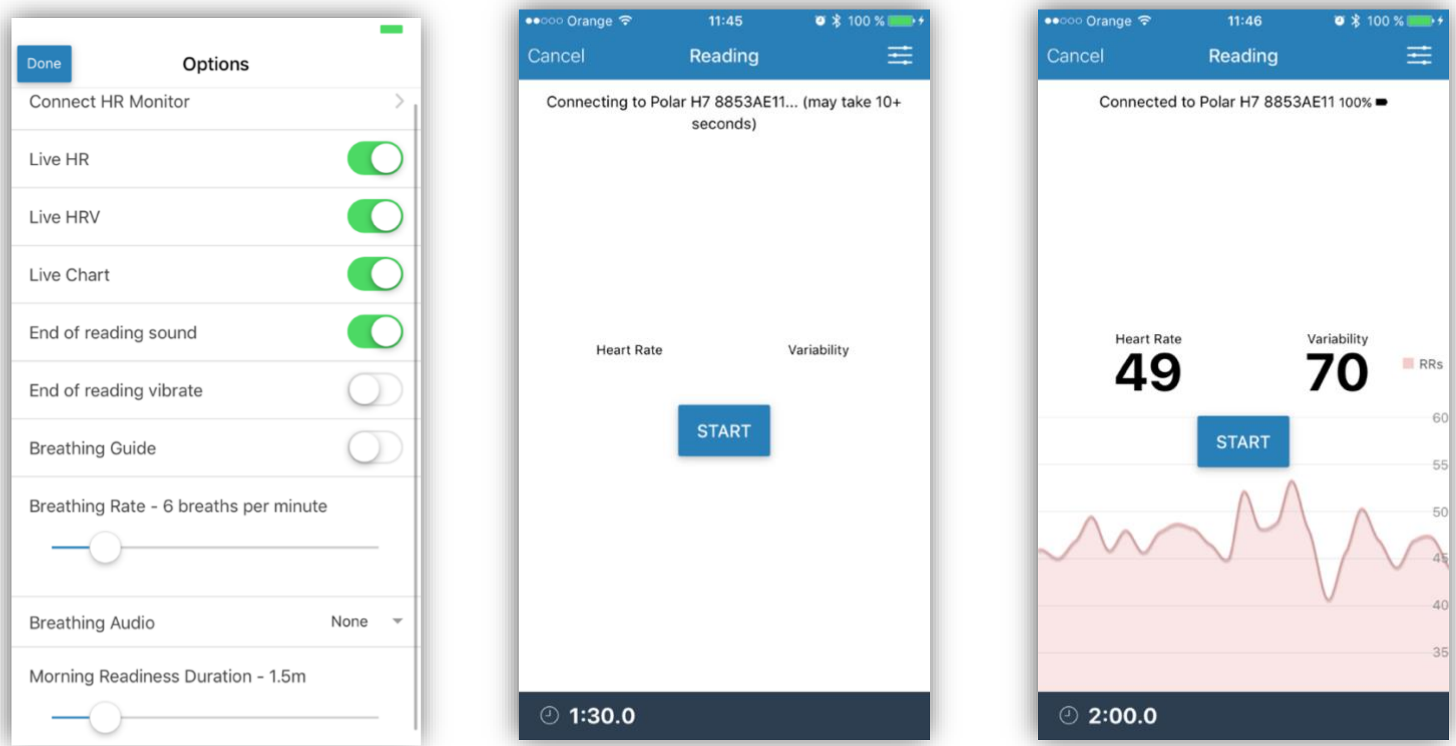

Figure 18. Elite HRV mobile application. From left to right: (1) Settings of the recording; (2) Connection with Polar H7 chest strap via Bluetooth; (3) Mobile application ready for the recording of HRV.

The last part of data acquisition and processing were performed with Kubios HRV software (Finland Eastern University, Kuopio, Finland).

Technology implemented in chapter 8:

In contrast to the use of a traditional chest strap to measure heart rate and HRV, photoplethysmography is an optical technique that can be used to detect blood volume changes in the microvascular bed of tissue. This technology has been validated to measure HRV. As mentioned, in this study HRV4training was used to measure and analyze HRV. HRV4training uses a mobile camera and a flash to detect blood volume changes and determine HRV. Different screenshots are displayed in figure 17 as an example of daily measurements.

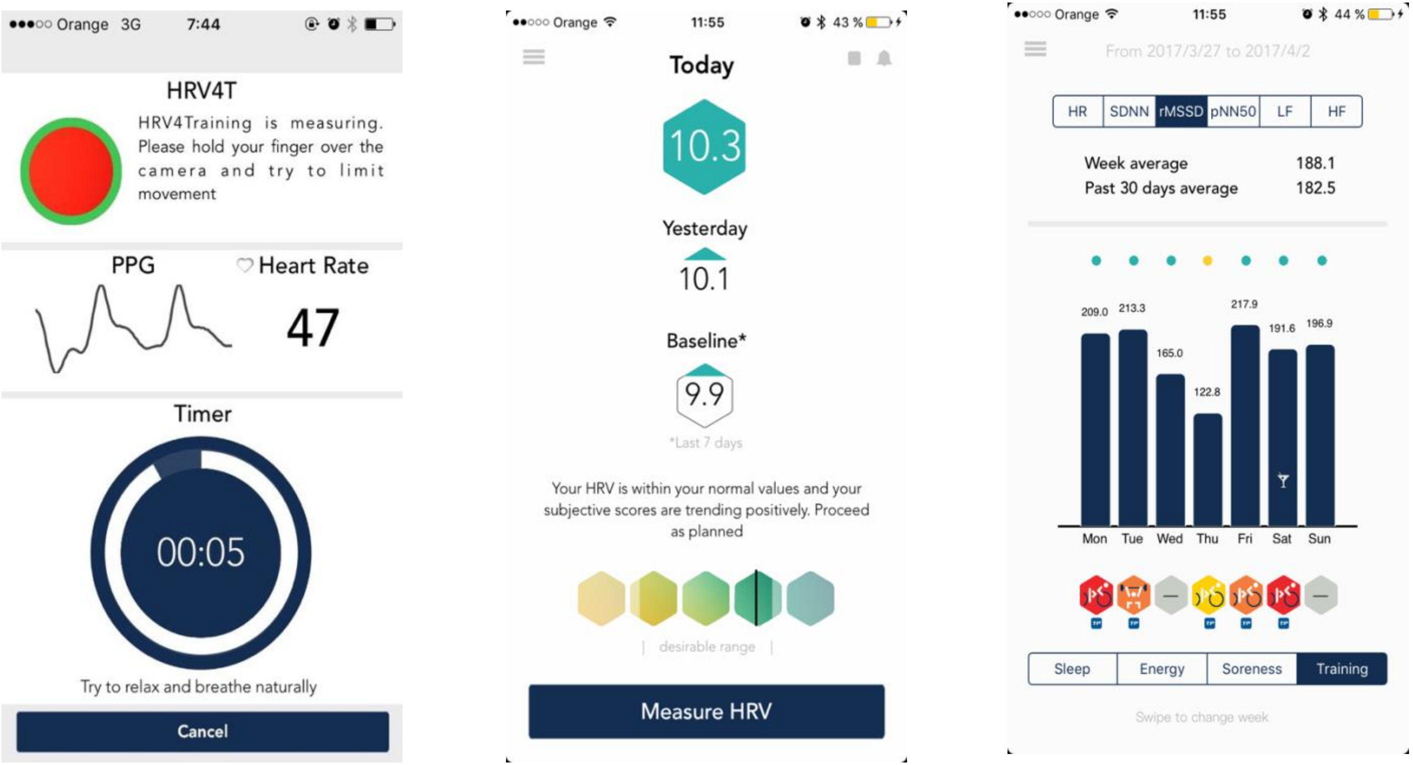

Figure 19. HRV4training mobile application. From left to right: (1) Live recording of HRV; (2) Daily recording with personalized fatigue information and training suggestion; (3) Weekly measures of RMSSD.

11.3 Appendix III. Specific spreadsheet for day-to-day training prescription.

As labelled in the method sections, HRV-G training was set daily based on the HRV measurements. The mathematical development to establish that was done with a specific spreadsheet. This spreadsheet was the main tool and can be found at: https://www.dropbox.com/s/jbosvpk9dv8jjgi/Spreadsheet-Annex3.xlsx?dl=0. All the figures displayed in this annex are extracted from this spreadsheet

The first step was to measure HRV during four weeks with the aim of establishing the SWC (figure 20). Furthermore, the SWC was updated every four weeks, as ANS may vary due to training.

Baseline weeks

WEEK	DAY	Date	rMSSD	LnrMSSD	7-Day_roll
1	MONDAY	15/2/19	128,77	4,858027867	4,858027867
1	TUESDAY	16/2/19	121,52	4,800078858	4,829053363
1	WEDNESDAY	17/2/19	126,93	4,843635753	4,83391416
1	THURSDAY	18/2/19	141,21	4,950248144	4,862997656
1	FRIDAY	19/2/19			4,862997656
1	SATURDAY	20/2/19	108,68	4,688407785	4,828079682
1	SUNDAY	21/2/19	121,42	4,79925561	4,82327567
2	MONDAY	22/2/19	134,83	4,904014726	4,830940146
2	TUESDAY	23/2/19	126,38	4,839293241	4,837475876
2	WEDNESDAY	24/2/19	155,8	5,048573133	4,871632106
2	THURSDAY	25/2/19	140,39	4,944424264	4,87066146
2	FRIDAY	26/2/19	156,9	5,05560866	4,897082488
2	SATURDAY	27/2/19	140,75	4,946985267	4,934022129
2	SUNDAY	28/2/19	135	4,905274778	4,949167724
3	MONDAY	1/3/19	142,3	4,957937505	4,956870978
3	TUESDAY	2/3/19	112,5	4,722953222	4,940250976
3	WEDNESDAY	3/3/19	97,5	4,579852378	4,873290868
3	THURSDAY	4/3/19	106,5	4,668144985	4,833822399
3	FRIDAY	5/3/19	202,5	5,310739887	4,870269717
3	SATURDAY	6/3/19	168,2	5,125153748	4,895722357
3	SUNDAY	7/3/19	110,8	4,707726774	4,867501214
4	MONDAY	8/3/19	117,9	4,769836808	4,840629686
4	TUESDAY	9/3/19	162,5	5,090678002	4,893161797
4	WEDNESDAY	10/3/19	115,9	4,75272775	4,917858279
4	THURSDAY	11/3/19	114,7	4,742320024	4,928454713
4	FRIDAY	12/3/19	93,3	4,535820108	4,817751888
4	SATURDAY	13/3/19	102,7	4,631812117	4,747274512
4	SUNDAY	14/3/19			4,753865801

Figure 20. Example of HRV data during the baseline weeks.

During the TW, HRV-G training was prescribed according to $rMSSD_{7day\text{-}rollavg}$. When $LnRMSSD_{7day\text{-}rollavg}$ fell outside SWC, high intensity training ceased. After returning inside SWC, high intensity training was prescribed again. In this spreadsheet, when $LnRMSSD_{7day\text{-}rollavg}$ falls below SWC, the day turns red. In contrast, when

$LnRMSSD_{7day\text{-}rollavg}$ goes above SWC, the day changes colour from white to green. An example can be found in figure 21.

WEEK	DAY	Date	rMSSD	LnrMSSD	7-Day_roll
5	MONDAY	15/3/19	127,3	4,846546506	4,766650751
5	TUESDAY	16/3/19	126,7	4,841822087	4,725174765
5	WEDNESDAY	17/3/19	118,6	4,775756487	4,729012888
5	THURSDAY	18/3/19	168,4	5,126342102	4,793016568
5	FRIDAY	19/3/19	152	5,023880521	4,87435997
5	SATURDAY	20/3/19	128,4	4,855150391	4,911583016
5	SUNDAY	21/3/19	113,4	4,730921391	4,885774212
6	MONDAY	22/3/19	106,4	4,667205577	4,860154079
6	TUESDAY	23/3/19	137,8	4,925803359	4,872151404
6	WEDNESDAY	24/3/19	125,9	4,835487941	4,880684469
6	THURSDAY	25/3/19	136,7	4,917788744	4,850891132
6	FRIDAY	26/3/19	149,5	5,007296393	4,848521971
6	SATURDAY	27/3/19	164,6	5,103518288	4,884003099
6	SUNDAY	28/3/19	145,4	4,979488565	4,919512695
7	MONDAY	29/3/19	113,9	4,73532087	4,929243451
7	TUESDAY	30/3/19	134,8	4,903792198	4,926099
7	WEDNESDAY	31/3/19	154,9	5,042779747	4,955712115
7	THURSDAY	1/4/19	146,5	4,987025428	4,96560307
7	FRIDAY	2/4/19	111,7	4,715816706	4,923963115
7	SATURDAY	3/4/19	144,1	4,970507503	4,904961574
7	SUNDAY	4/4/19	111,7	4,715816706	4,867294166
8	MONDAY	5/4/19	144,1	4,970507503	4,900892256
8	TUESDAY	6/4/19	119,2	4,780802755	4,883322336
8	WEDNESDAY	7/4/19	147,4	4,99314998	4,876232369
8	THURSDAY	8/4/19	116,6	4,758749274	4,843621489
8	FRIDAY	9/4/19	97,4	4,578826211	4,824051419
8	SATURDAY	10/4/19	109,3	4,694096395	4,784564118
8	SUNDAY	11/4/19	115,1	4,745801316	4,788847633
9	MONDAY	12/4/19	99,7	4,602165677	4,736227372
9	TUESDAY	13/4/19	184	5,214935758	4,798246373
9	WEDNESDAY	14/4/19	134,1	4,89858579	4,784737203

Figure 21. HRV daily recordings during training weeks (TW). When $LnRMSSD_{7day\text{-}rollavg}$ 7-day_roll in the (spreadsheet) falls outside SWC, the cell changes its colour (when $LnRMSSD_{7day\text{-}rollavg}$ falls below SWC, the day turns red. In contrast, when $LnRMSSD_{7day\text{-}rollavg}$ goes above SWC, the day changes colour from white to green).

"Do not go gentle into that good night,
Old age should burn and rave at close of day;
Rage, rage against the dying of the light.

Though wise men at their end know dark is right,
Because their words had forked no lightning they
Do not go gentle into that good night.

Good men, the last wave by, crying how bright
Their frail deeds might have danced in a green bay,
Rage, rage against the dying of the light.

Wild men who caught and sang the sun in flight,
And learn, too late, they grieved it on its way,
Do not go gentle into that good night.

Grave men, near death, who see with blinding sight
Blind eyes could blaze like meteors and be gay,
Rage, rage against the dying of the light.

And you, my father, there on the sad height,
Curse, bless, me now with your fierce tears, I pray.
Do not go gentle into that good night.
Rage, rage against the dying of the light."

Dylan Thomas.