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Programa de Doctorado en Deporte y Salud

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

Doctoral thesis

A dissertation presented by

Alejandro Javaloyes Torres

Elche, 2019

UNIVERSITAS
Miguel Hernández

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.

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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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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. 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

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- 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.

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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.

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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]

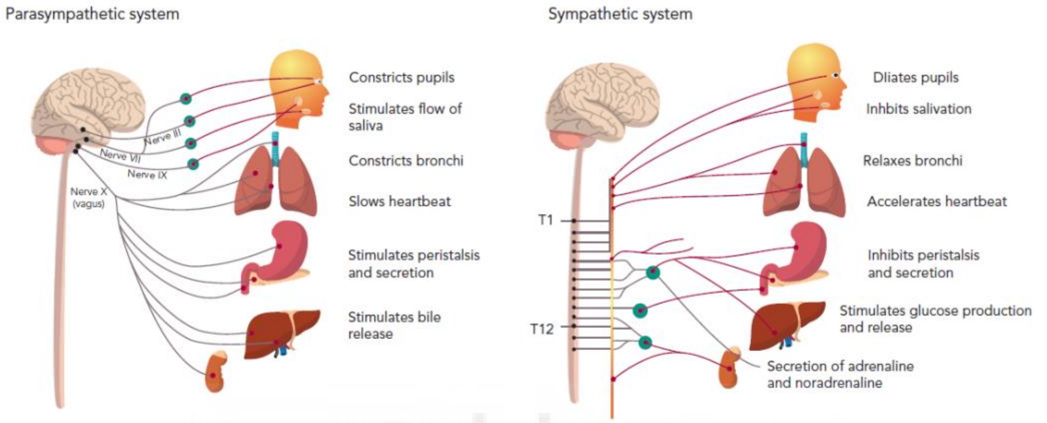
Parasympathetic system
Nerve III
Nerve VII
Nerve IX
Nerve X (vagus)
Constricts pupils
Stimulates flow of saliva
Constricts bronchi
Slows heartbeat
Stimulates peristalsis and secretion
Stimulates bile release
Sympathetic system
T1
T12
Dliates pupils
Inhbits salivation
Relaxes bronchi
Accelerates heartbeat
Inhibits peristalsis and secretion
Stimulates glucose production and release
Secretion of adrenaline and noradrenaline

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

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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

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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.

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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.

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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

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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 $\text{LnRMSSD}_{\text{7day-roll-avg}}$ 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]

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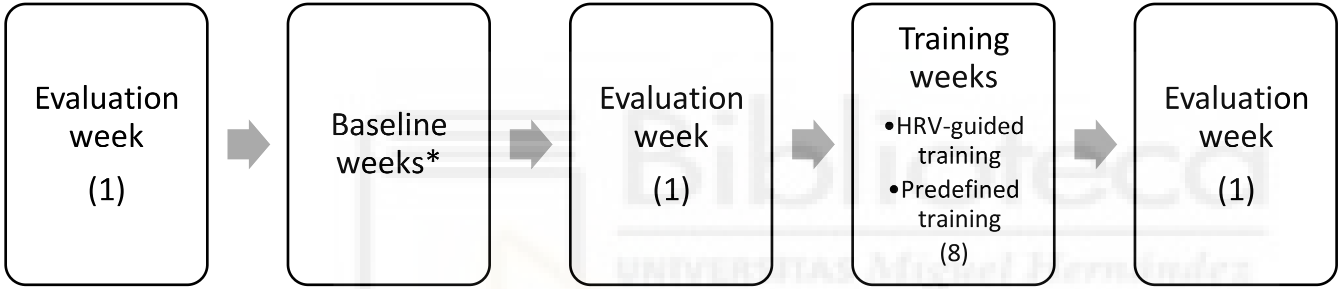
Evaluation week
(1)
Baseline weeks*
Evaluation week
(1)
Training weeks
•HRV-guided training
•Predefined training
(8)
Evaluation week
(1)

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).

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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.

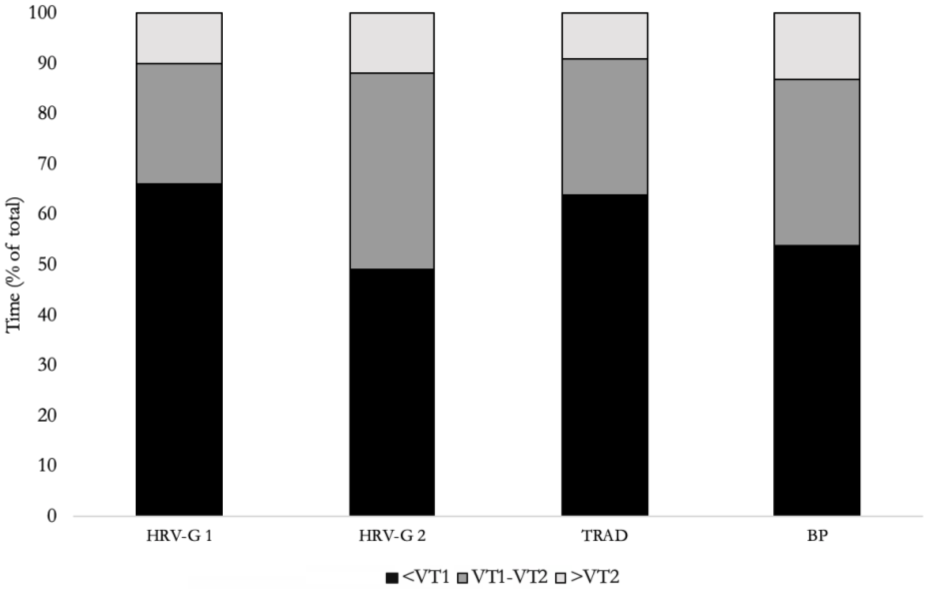

Figure 3. Training intensity distribution during training weeks (TW) in the groups that participated in the studies.

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.

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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.

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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.

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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.

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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.

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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).

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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)

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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

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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.

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

PART III

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11. APPENDICES

11. Appendices

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

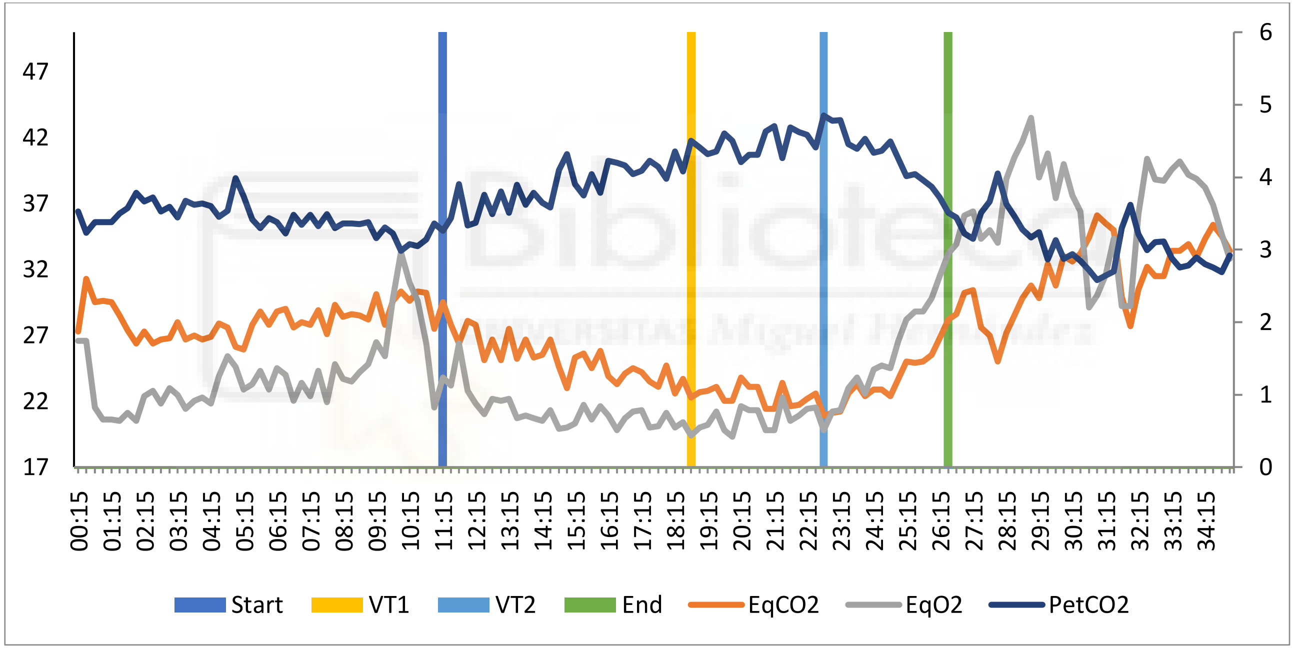


Figure 14. Detection of the first and second ventilatory threshold (VT1, VT2) using CO2 and O2 equivalents (EqCO2, EqO2) and Partial pressure of CO2 (PetCO2).

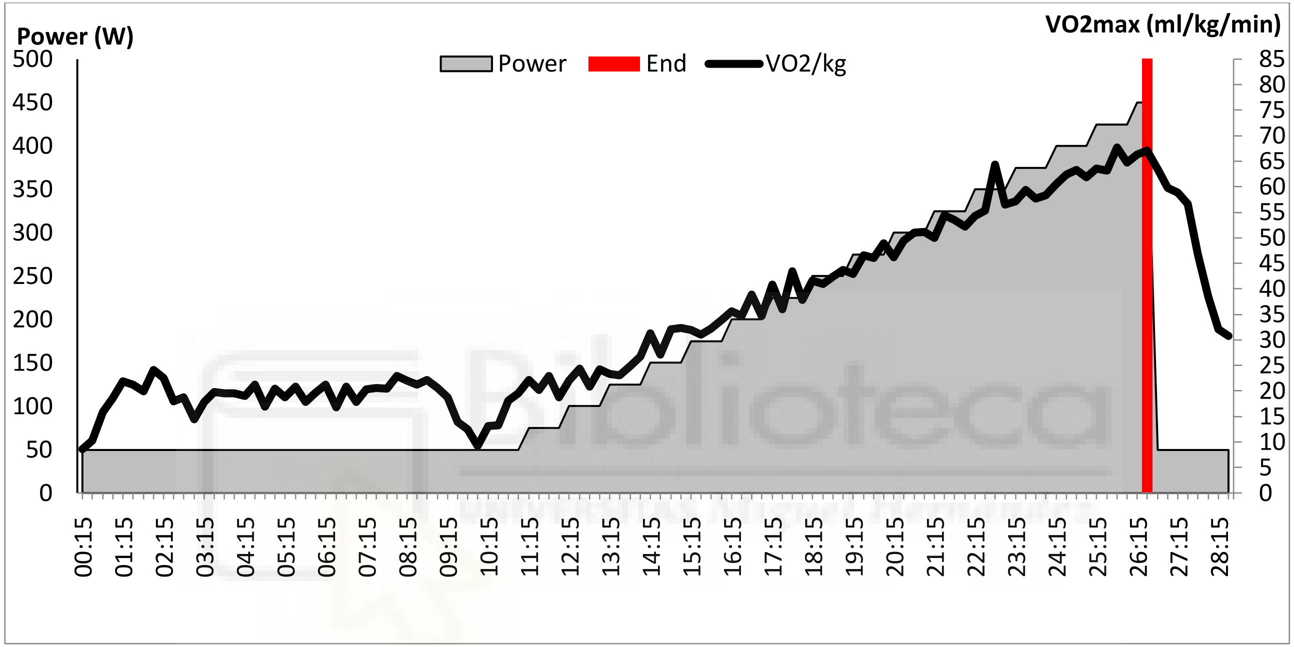


Figure 15. Detection of VO2max.

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.

Technology implemented in chapter 7:

Step 1: Fitting the strap onto the chest.

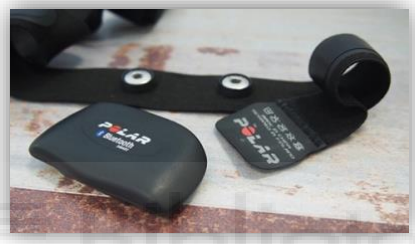


Figure 16. Chest strap Polar H7 (Polar Team System, Polar Electro Oy, Kempele, Finland).

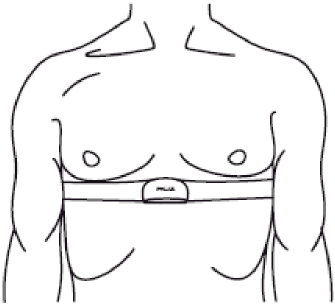
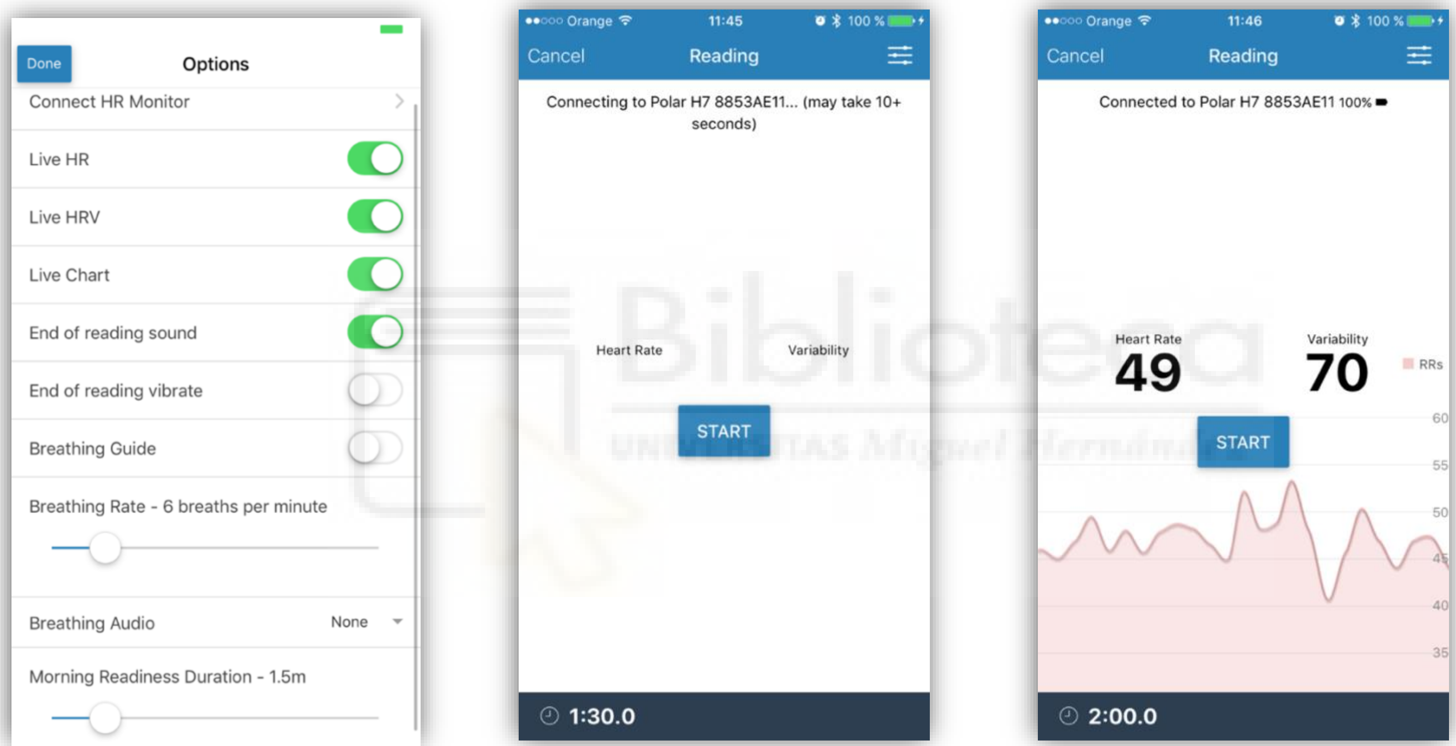


Figure 17. Correct position of the chest strap (according to the manufacturer's recommendation).

Step 2: Measuring HRV with Elite HRV mobile application



Done
Options

Connect HR Monitor

Live HR ●

Live HRV ●

Live Chart ●

End of reading sound ●

End of reading vibrate ○

Breathing Guide ○

Breathing Rate - 6 breaths per minute

Breathing Audio None

Morning Readiness Duration - 1.5m

●●○○○ Orange
11:45
100 %
Cancel
Reading

Connecting to Polar H7 8853AE11... (may take 10+ seconds)

Heart Rate
Variability
START
1:30.0
●●○○○ Orange
11:46
100 %
Cancel
Reading

Connected to Polar H7 8853AE11 100%

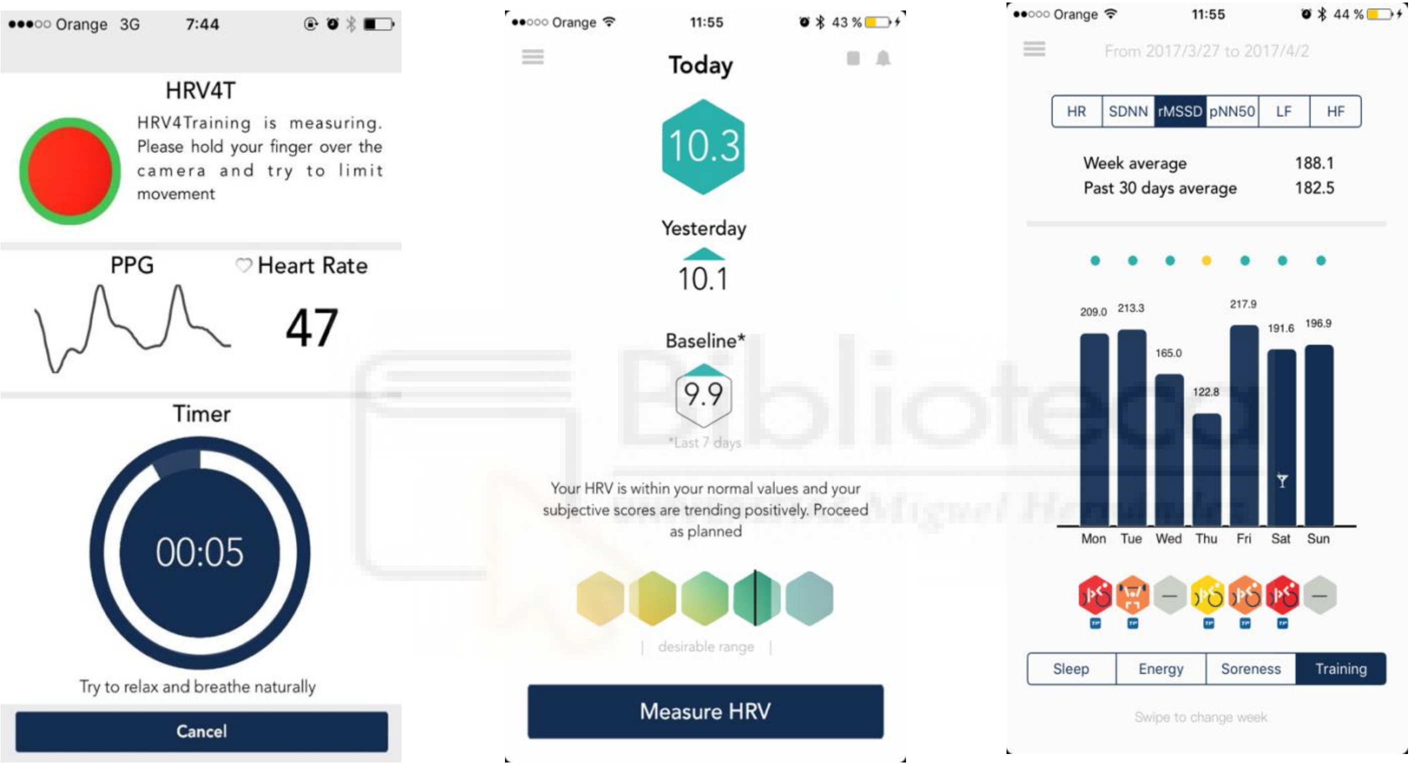
Heart Rate
49
Variability
70
RRs
START
60
55
50
45
40
35
2:00.0

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.


●●●○○ Orange 3G 7:44
HRV4T
PPG
♡ Heart Rate
47
Timer
00:05
Cancel
●●○○○ Orange 11:55 43 %
Today
10.3
Yesterday
10.1
Baseline*
9.9
*Last 7 days
desirable range
Measure HRV
●●○○○ Orange 11:55 44 %
From 2017/3/27 to 2017/4/2
HR
SDNN
rMSSD
pNN50
LF
HF
209.0
213.3
165.0
122.8
217.9
191.6
196.9
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Sleep
Energy
Soreness
Training
Swipe to change week

HRV4Training is measuring. Please hold your finger over the camera and try to limit movement

Try to relax and breathe naturally

Your HRV is within your normal values and your subjective scores are trending positively. Proceed as planned

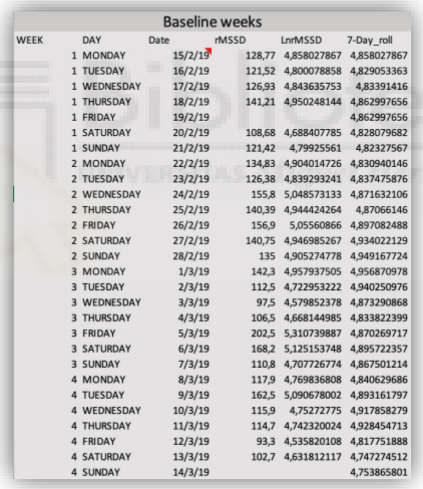
Week average 188.1
Past 30 days average 182.5

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.



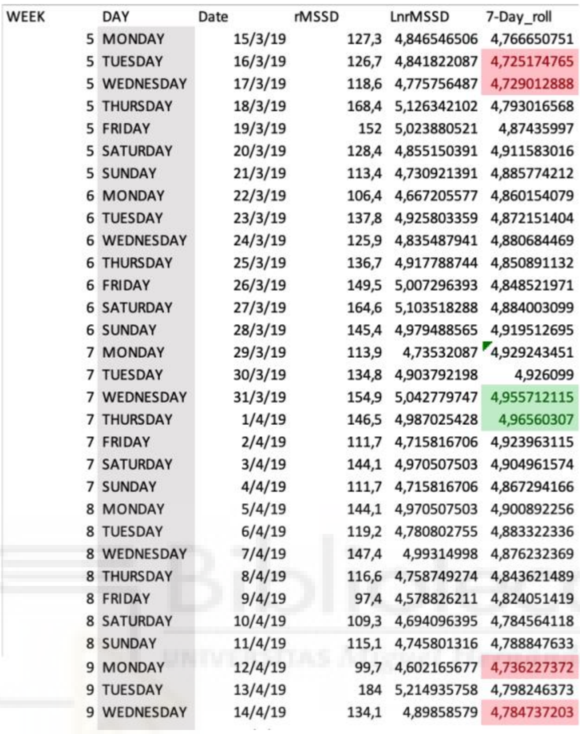
Baseline weeks

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 $\text{rMSSD}_{\text{7day-rollavg}}$. When $\text{LnRMSSD}_{\text{7day-rollavg}}$ fell outside SWC, high intensity training ceased. After returning inside SWC, high intensity training was prescribed again. In this spreadsheet, when $\text{LnRMSSD}_{\text{7day-rollavg}}$ falls below SWC, the day turns red. In contrast, when

LnRMSSD$_{\text{7day-rollavg}}$ 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$_{\text{7day-rollavg}}$ 7-day_roll in the (spreadsheet) falls outside SWC, the cell changes its colour (when LnRMSSD$_{\text{7day-rollavg}}$ falls below SWC, the day turns red. In contrast, when LnRMSSD$_{\text{7day-rollavg}}$ 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.