Training Prescription Guided by Heart Rate Variability Vs. Block Periodization in Well-Trained Cyclists

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Abstract

Javaloyes, A, Sarabia, JM, Lamberts, RP, Plews, D, and Moya-Ramon, M. Training prescription guided by heart rate variability vs. block periodization in well-trained cyclists. *J Strength Cond Res* 34(6): 1511–1518, 2020—Predefined training programs are common place when prescribing training. Within predefined training, block periodization (BP) has emerged as a popular methodology because of 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 2 groups: an HRV-guided group and a BP group, and they completed 8 training weeks. Cyclists completed 3 evaluations weeks, before and after each period. During the evaluation weeks, cyclists performed: (a) a graded exercise test to assess $\dot{V}O_2$max, peak power output (PPO), and ventilatory thresholds with their corresponding power output (VT1, VT2, WVT1, and WVT2, respectively) and (b) a 40-minute simulated time-trial (40 TT). The HRV-guided group improved $\dot{V}O_2$max ($p = 0.03$), PPO ($p = 0.01$), WVT2 ($p = 0.02$), WVT1 ($p = 0.01$), and 40 TT ($p = 0.04$). The 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.

Key Words: 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 that 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 (20). Block periodization consists of training cycles of well-concentrated workloads (19), and there is a large body of research that supports its effectiveness (1,7,16,19,20,41,42). 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 (19,20).

The BP method is used in many sports ranging from kayaking to cycling. In kayaking (1,16) and cross-country skiing (7), BP lead to larger improvements in fitness and performance than multitargeted traditional training prescription. In road cycling, BP has shown to results in greater improvements in $\dot{V}O_2$max, power output at 2 mmol·L^{-1}, and 40-minute time-trial performance (41,42,47).

However, most of the research around predefined training programs shows interindividual variation with some subjects responding better than others or, in some cases, subjects not responding (4,23). In the field, the monitoring of predefined training programs is generally performed by measures of training load. However, changes in predefined training due to the unexpected response of the athlete are based on subjective criteria of the coach and the athlete. Although coaches play a vital 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 have substantially grown. This development also has created the opportunity to individualize and adapt training programs to prescribe the most effective training programs. One of the new promising tools to monitor and fine-tune training is heart rate variability (HRV). Heart rate variability has shown to be a valid and reliable tool to assess cardiac autonomic regulation (17), which can reflect positive and negative adaptation to training programs (48). and to reflect fatigue induced by training or other daily stressors (2).

Owing to the development of new methodologies (shorter recordings) and technologies (mobile apps) for collecting HRV (i.e., shorter recordings, simple analysis) (11,12,40), it is possible to measure HRV on a daily basis. Heart rate variability has been used to prescribe training in running (3,24,49), cross-country skiing (46), and road cycling (21). 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 or in the training intensity (31). In cyclists, Javaloyes et al. (21) showed greater increments in performance in well-trained cyclists trained based on HRV-guided training program compared with a standardized program without HRV. Nuuttila et al. (31) reported similar benefits in performance when

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using either an HRV-guided or BP-guided training program in recreational runners.

However, to the best of 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 an 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 2 periods: (a) a baseline period (BW) and (b) 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 ($\dot{V}O_2$max and performance) and assigned to a HRV-guided training group (HRV-G, $n = 8$) or a BP training group (BP, $n = 7$). During the following 8 weeks, the cyclists were trained based on the group they were allocated to. Cyclists in the HRV-G group were trained according to their HRV morning values, whereas BP cyclists were trained based on a predetermined training program. There were 3 evaluation weeks (EWs): PRE (before BW), MID (between BW and TW), and POST (after TW). Each EW consisted of 2 testing sessions with a 48-hour recovery period. The first testing session included a maximal graded exercise and a 40-minute simulated time trial.

Subjects

Twenty well-trained cyclists (ranging from 18 to 46 years old) with at least a 2-year personalized training history were recruited for this study. To be included in the final analysis, subjects had to complete (a) at least the 90% of the training program and daily HRV measurements and (b) all the HRV records on the day they had high-intensity training. The general characteristics of the subjects that were included for analyses are shown in Table 1. Subject characteristics were measured mean ± *SD*. Before taking part in the study, all subjects were fully informed about the study requirements and signed 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.

Procedures

Graded Exercise Test. $\dot{V}O_2$max, first ventilatory threshold (VT1), and second ventilatory thresholds (VT2) were calculated with a maximal graded exercise test (GXT). The test started with a 10-minute warm-up at 50 W, followed by a 25-W increase every minute (step protocol) until exhaustion (32). Subjects performed all the tests on their own bike, which was fitted on a Wahoo Kickr Power Trainer (50). The Wahoo Kickr Power Trainer was calibrated in each test during the 10-minute warm-up according to the manufacturer's recommendation. Subjects were allowed to cycle at their own preferred cadence. The GXT 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 $\dot{V}O_2$max was calculated as the highest 30-second $\dot{V}O_2$ average (34). For the determination of VT1 and VT2, the 15-second 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-Minute Time-Trial. The performance was assessed using a 40-minute all-out time-trial (40 TT) in the laboratory. Before the start of the 40 TT, a 10-minute warm-up was performed at a constant work of 50 W. Calibration of the GXT was performed 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 40 TT 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 was determined by the mean power output during the 40 TT.

Heart Rate Variability Measurements. All subjects were instructed to measure their pulse-rate intervals upon waking up and emptying their urinary bladder, both during the BW and the TW period. The HRV measurements were captured with the phone/flash over the fingertip through the HRV4Training smartphone application (see http://www.hrv4training.com) (40). Heart rate variability was measured in a supine position and over a 90-second period (11). Cyclists were instructed to lie still and to not perform any further activity during the recordings, and the last 60 seconds of the HRV measurement were captured (14). During the analysis of the signal, the application processed and discarded the artifacts and the ectopic beats. In cases where the record had erroneous signals or too much noise (i.e., excessive movement of the athlete's finger), the record was discarded and repeated immediately until an optimal record was obtained. The root mean-squared differences of successive RR intervals (RMSSD) were chosen as the vagal index, based on its greater suitability and reliability than other indexes. The HRV data were transformed by taking the natural logarithm to allow for 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 (28). During the BW, the smallest worthwhile change (SWC) of LnRMSSD was calculated as mean ± 0.5 × *SD* (49). The smallest worthwhile change was updated after the first 4 weeks of TW because of the relationship between CAR and the adaptation to training (2). Thus, the SWC for the past 4 weeks was calculated with the LnRMSSD of the previous 4 weeks of TW. This SWC was used for the interpretation of changes in

Table 1
Subject characteristics.*

	BP ($n = 8$)	HRV-G ($n = 7$)
Years	30.8 ± 10.5	28.1 ± 13.2
Training experience (y)	11.4 ± 3.1	11.3 ± 3.0
Height (m)	1.78 ± 0.05	1.74 ± 0.05
Body mass (kg)	72.6 ± 10.4	73.8 ± 4.6
$\dot{V}O_2$max	59.0 ± 6.2	58.9 ± 5.6

*BP = block periodization.

$LnRMSSD_{7day\text{-}roll\text{-}avg}$ and the subsequent training prescription during the following 4 weeks.

Heart Rate Variability Vs. Block Periodization 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 before 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 before the beginning of the study. The training sessions and periodization of the BP group are shown in Figure 1, including low training sessions (low; intensity < VT1), high-intensity training (≥VT2), and high-intensity interval training (HIIT; >VT2). The training blocks consist 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 1 HIIT session).

For the HRV-G group, training in TW was prescribed according to their HRV morning values following a decision-making schema (24) (Figure 2). Cyclists only performed 2 consecutive sessions of high-intensity training and did not accumulate more than 2 consecutive days of rest. When $LnRMSSD_{7day\text{-}roll\text{-}avg}$ fell outside the SWC, training intensity changed from high-intensity training to low-intensity training or rest. Typical training sessions are displayed in Figure 1; high-intensity training sessions were performed with a 45–60 minute warm-up and 20 minutes of cooling-down period.

Training load was calculated (in arbitrary units [AU]) with a training impulse formula (28) that takes volume (time) and intensity into account: TRIMP (AU) = (Time [s] below VT1 × 1) + (time [s] between VT2 and VT2 × 2) + (time [s] above VT2). Training sessions were daily monitored by specific training software (TrainingPeaks, Boulder, CO, USA).

Statistical Analyses

The homogeneity of the data was tested with a Levene's test, whereas the normal distribution was checked using a Shapiro-Wilk test. Based on the normal distribution, the data are presented as mean ± *SD*. A repeated-measure analysis of variance (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 analyzed for practical significance using magnitude-based inferences (MBI) both within- and between-group comparison (18). 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 were 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 (0.5–5%); unlikely (5–25%); possible (25–75%); likely (75–95%); very likely (95–99.5%); and most likely (>99.5%) (18). If the 90% CL overlapped small positive or negative values, the magnitude of change was labeled unclear. Results were analyzed 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 MBI 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 because of injuries ($n = 1$) and insufficient compliance (<90%) with the training program or the HRV measurements ($n = 4$).

In the BW, there were no statistical differences in volume or 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 hours 06 minutes ± 3 hours 04 minutes for HRV-G and 11 hours 22 minutes ± 3 hours 07 minutes 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-group difference in percentage of time expended below VT1 ($p = 0.62$; $d = -0.26$ [−1.35; 0.83]; unclear),

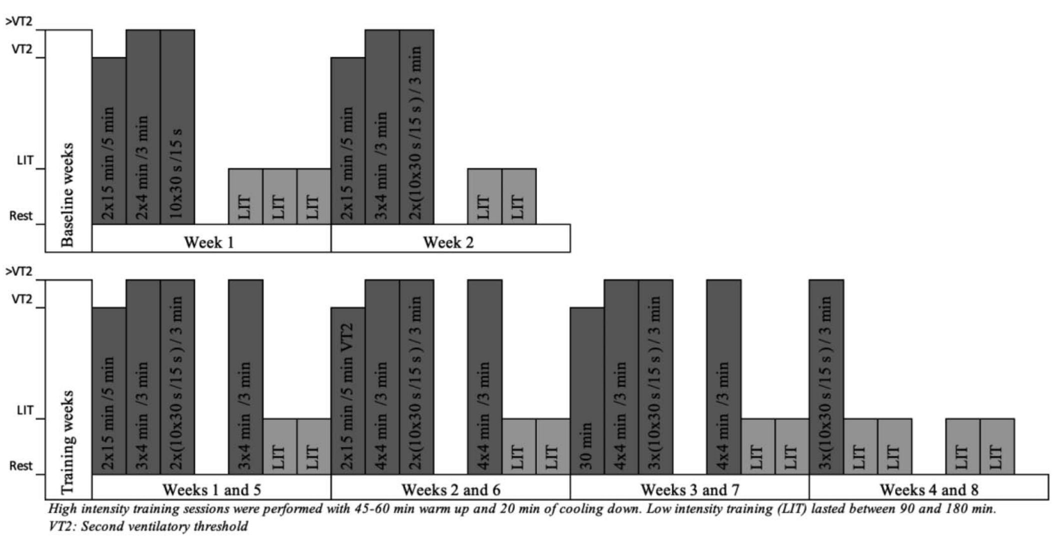

Figure 1. Description of the training program during baseline weeks and for the block periodization group during training weeks.

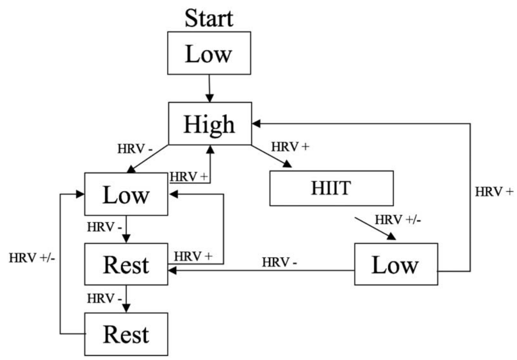

Figure 2. HRV-guided training decision-making schema (19). HRV = heart rate variability.

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-group training load (AU) weekly average did not differ: 1,033.28 ± 312.51 AU and 1,028.81 ± 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, whereas standardized change is showed in Figure 3. The HRV-G group improved $\dot{V}O_2$max (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 40 TT (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), whereas $\dot{V}O_2$max, PPO, WVT1, and 40 TT remained unchanged. However, MBI reported likely beneficial effects for $\dot{V}O_2$max (Table 2).

Individual changes in endurance performance (40 TT) showed that only 1 subject in the HRV-G group decreased his performance (−0.5%), whereas in the BP group, 3 subjects reported lower power output during 40 TT by −11.6%, −9.1% and −2.7%. Furthermore, most substantial individual changes were for the HRV-G group (Figure 3).

For all the variables measured during the EW ($\dot{V}O_2$max, PPO, WVT1, WVT2, and 40 TT), 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 $\dot{V}O_2$max ($d = 0.10$ [−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 40 TT ($d = -0.10$ [−0.87; 0.86]).

LnRMSSD did not differ between BW and TW in both groups. However, LnRMSSD showed significant decrease in BP (4.01 ± 0.76) compared with HRV-G (4.57 ± 0.56) in TW despite comparable values in BW (4.44 ± 1.15 and 4.61 ± 0.61 for BP and HRV-G, respectively) (Figure 4). By contrast, coefficient of variation (CV) showed a significant increase in BP from BW (7.11 ± 4.59%) to TW (10.54 ± 4.91%), whereas HRV-G showed similar values in BW (5.19 ± 3.48%) and TW (6.10 ± 3.37%). Furthermore, BP showed significant CV than HRV-G in TW (Figure 4).

Discussion

This study was to compare the day-to-day training prescription based on daily HRV measurements with traditional BP 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 BP. Also, this study was conducted with new technology that facilitates daily monitoring of HRV.

Training volume was similar between groups and training intensity distribution. Also, TRIMP remained similar between groups in TW. Similarly, other studies (31) have also reported equal intensity distribution and amount of training in an HRV-guided training group and a BP 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 with 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 (10) and well-trained athletes (21). However, these studies are performed with multitargeted 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 $\dot{V}O_2$max (22,29). In this study, the HRV-G group improved $\dot{V}O_2$max (3 ± 3%; $p = 0.03$). Qualitative assessment based on the standardized change reported likely beneficial effects for both groups (Table 2). This result matches that observed in earlier studies reporting increments in $\dot{V}O_2$max for untrained (10), recreationally (31,48), and elite (46) endurance athletes who followed an HRV-guided training. However, Javaloyes et al. (21), also in well-trained cyclists, did not report increments in $\dot{V}O_2$max for HRV-guided training. These observed differences may be because cyclists completed a higher proportion of time at high intensities (≥VT2) in this study, obtaining greater increments in

Table 2
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
$\dot{V}O_2$max	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
40 TT	262 ± 30	264 ± 33	24/64/12	Possibly trivial	261 ± 28	280 ± 39†	91/8/1	Likely beneficial

*BP = block periodization; PPO = peak power output; WVT2 = power output at VT2 intensity; WVT1 = power output at VT1 intensity; 40 TT = power output during the 40-min time-trial.
†$p < 0.05$.
‡$p < 0.01$.

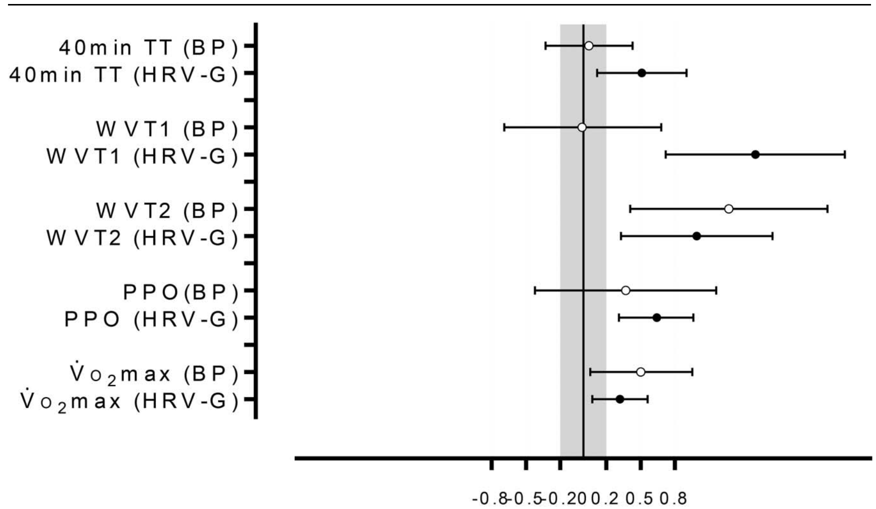

Figure 3. Standardized change for both groups (Cohen's *d*). PPO = peak power output; WVT2 = power output at VT2 intensity; WVT1 = power output at VT1 intensity; 40 TT = power output during the 40-minute time-trial.

this variable. Regarding BP, our results are in line with those reported in cyclists of similar training status (41,42). It can therefore be assumed that both periodization models led to improvements in $\dot{V}O_2$max. This explains around the unclear between-group results when using the MBI statistical method.

Peak power output in this study was obtained at $\dot{V}O_2$max intensity, which has been shown to be another strong determinant of aerobic performance of endurance athletes (22,35). In this study, PPO only improved in the HRV-G group with no change in the BP group. Also, the HRV-G group reported very likely beneficial effects with a 98% chance of benefit; in comparison, the BP group exhibited possible beneficial effects (65% chance of benefit, Table 2). These findings are in line with those reported previously (21), which found greater increments in this variable in well-trained cyclists. Although 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 conducted 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 3). It has been previously reported that both, a day-to-day training prescription based on HRV measurements and a traditional periodization, lead to increments regarding these parameters in well-trained cyclists (21).

WVT1 increased in the HRV-G but not in the BP group. Furthermore, MBI reported more considerable 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 3). 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 (40 TT) increased in the HRV-G but not in the BP group. Furthermore, the qualitative assessment showed likely beneficial effects for the HRV-G, whereas in the BP group, it reported possibly trivial effects. In a recent study (21), HRV-G showed similar improvements in performance. The results obtained in the BP group differ from other results (41) that reported improvements in performance in well-trained cyclists. A possible explanation is the mentioned study was conducted during a 12-week period, whereas the TW lasted 8 weeks. Thus, a longer

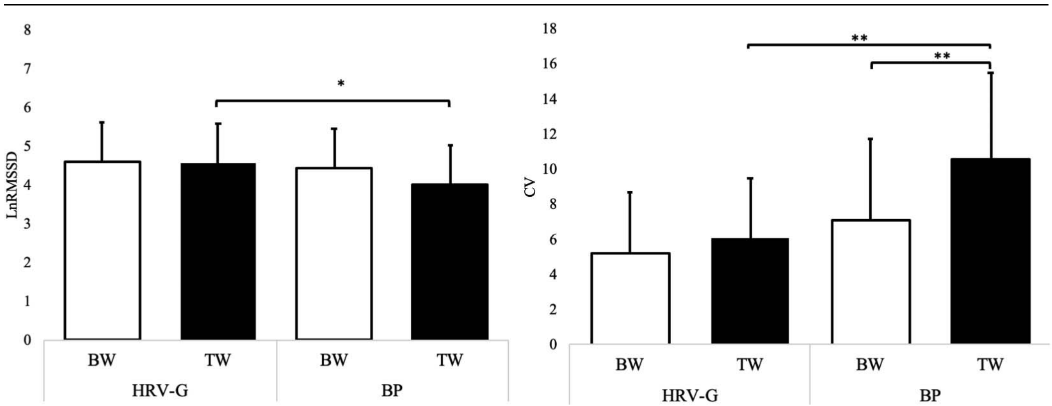

Figure 4. Mean Ln RMSSD and coefficient of variation (CV) for HRV-G and BP during baseline weeks (BW) and training weeks (TW). *p < 0.05; **p < 0.01. BP = block periodization.

duration could produce greater improvements in performance with BP 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 of greater training quality. Individual changes in 40 TT reported only 1 subject with a decrease in performance for the HRV-G, whereas the BP group presented 3 subjects with less power output in POST (Figure 5). 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 (26,27). As such, these well-trained cyclists have more probability to increased his performance in a 40-minute all-out effort by following a day-to-day training based on HRV measurements.

Heart rate variability was different in both groups. First, LnRMSSD reported lower values for BP than HRV-G during TW. Furthermore, during TW LnRMSSD was greater in BP than HRV-G. LnRMSSD, and CV has been proposed as a potential tool for the evaluation of training response (13,37,38). A decrease in LnRMSSD is associated with an overload training period or negative training response (25). Increases in CV are associated with poor response to training (5,8,15). In this study, the BP showed lower LnRMSSD than HRV-G in TW despite similar values in BW. These results are in accordance with those reported previously that found higher variation in predefined training programs than HRV-guided training (19,39).

In this study, the time-domain measure $\text{LnRMSSD}_{\text{7day-roll-avg}}$ assessed in the morning upon awakening was the variable chosen for the daily training prescription. The selection of this vagal-related measure was based on the recommendations of Plews et al. (36,37,39) and Buchheit (9) and on methodological characteristics such as the facilities of data acquisition through smartphone applications (12,40), the possibility of shorter recordings (30,33), and because it is less affected by breathing patterns than frequency-domain variables (43). Other authors chose the frequency-domain analysis of HRV for the purpose of training prescription (24,46). The frequency domain has been suggested as a measure of different types of "fatigue" (45), whereas the time-domain rMSSD may identify a global "fatigue" (44). Thus, the frequency-domain analysis may help to obtain a correct adjustment of the training program. Nevertheless, frequency domain requires more methodological considerations than the time-domain analysis, which could be more complex to implement in the daily monitoring of athletes. First, the time-domain analysis is less affected by breathing patterns than the frequency-domain analysis (43). Second, the frequency-domain analysis requires a longer window duration than time-domain analysis (6). Although a longer recording could provide more information, cyclists are more likely to perform shorter measurements with normal breathing patterns because they produce fewer disturbances in their daily routine.

Periodization theories and, consequently, predefined training programs 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 (23). Block periodization consists of training cycles of concentrated and specialized workloads (20). Despite the beneficial effects reported by BP models, concentrated workloads without valid and reliable measures of the response to training could lead to an overreached state that limits training adaptation. In this study, HRV was used to determine whether athletes were able to perform high-intensity training. If HRV decreased below

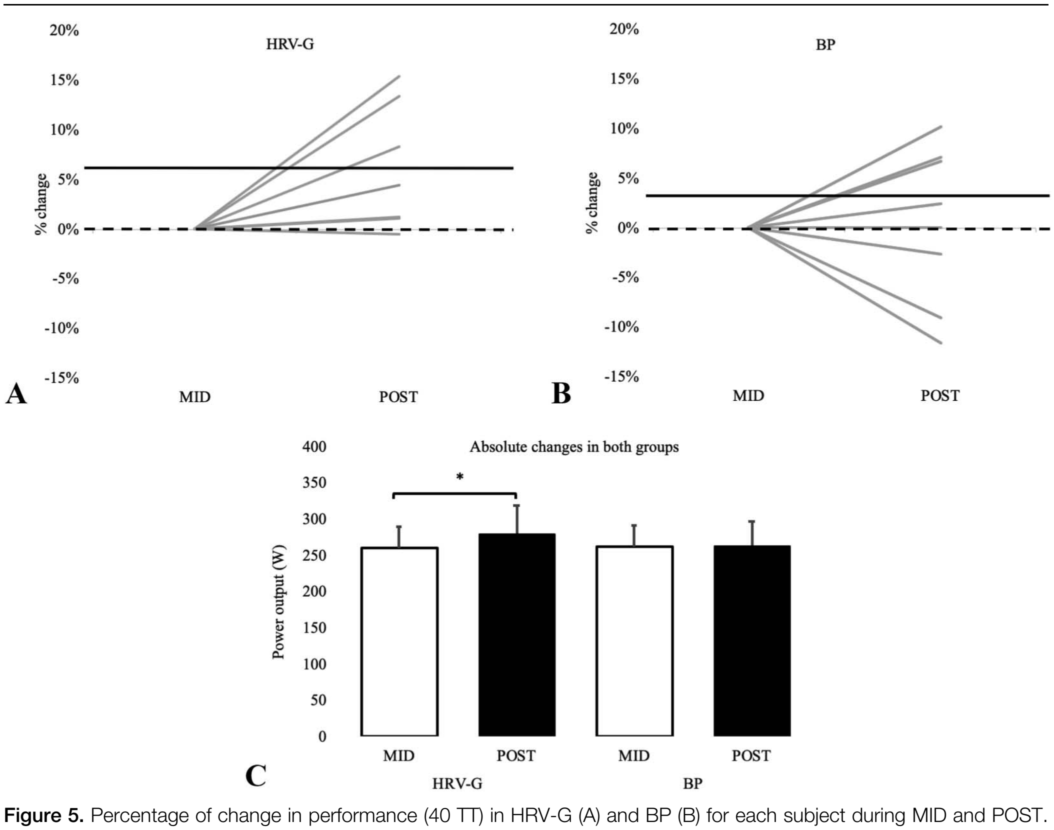

Figure 5. Percentage of change in performance (40 TT) in HRV-G (A) and BP (B) for each subject during MID and POST. Horizontal dashed lines are the zero levels. Horizontal solid lines represent mean change in each group. C) Absolute change in both groups. *$p < 0.05$. BP = block periodization.

smallest worthwhile change, high-intensity training was ceased until HRV returned inside the smallest worthwhile change. Heart rate variability–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 optimal cardiac autonomic homeostasis could lead to an improved adaptive response to training.

Monitoring HRV on a daily basis may provide useful information on adaptation and fatigue in athletes. The validity observed in ultrashort recordings of time-domain indices (12) and the development of validated mobile applications (12,40) have allowed for 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 standardized differences when compared with electrocardiogram (40). Thus, the combination of ultrashort measurements and easy-of-use applications could mean that athletes would be much more likely to comply with daily recordings (39).

The evidence from this study gives 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 practical methodologies to change the training prescription on a daily basis could lead to better timing in prescription, thereby giving greater insight into the programming puzzle and optimizing training regimes to enhance both fitness and performance. The optimization of training programs using tools to understand the individual response to training plays a vital role in the success during competition, especially in individual sports where physical condition is the leading 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.

Practical Applications

The practical application for coaches and athletes worthy of mention. First, the HRV measurements were taken with ultrashort 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 fact makes the measurement more comfortable for the athletes than the former alternative methods such as heart rate straps and electrocardiogram. 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 were collected daily using cloud service of the applications both for HRV measurements (HRV4Training) and the training process (TrainingPeaks). This is an essential part in the cyclists because 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.

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