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# Training Prescription Guided by Heart-Rate Variability in Cycling

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***Purpose:*** Road cycling is a sport with extreme physiological demands. Therefore, there is a need to find new strategies to improve performance. Heart-rate variability (HRV) has been suggested as an effective alternative for prescribing training load against predefined training programs. The purpose of this study was to examine the effect of training prescription based on HRV in road cycling performance. ***Methods:*** Seventeen well-trained cyclists participated in this study. After an initial evaluation week, cyclists performed 4 baseline weeks of standardized training to establish their resting HRV. Then, cyclists were divided into 2 groups, an HRV-guided group and a traditional periodization group, and they carried out 8 training weeks. Cyclists performed 2 evaluation weeks, after and before a training week. During the evaluation weeks, cyclists performed a graded exercise test to assess maximal oxygen uptake, peak power output, and ventilatory thresholds with their corresponding power output (VT1, VT2, WVT1, and WVT2, respectively) and a 40-min simulated time trial. ***Results:*** The HRV-guided group improved peak power output (5.1% [4.5%]; $P = .024$), WVT2 (13.9% [8.8%]; $P = .004$), and 40-min all-out time trial (7.3% [4.5%]; $P = .005$). Maximal oxygen uptake and WVT1 remained similar. The traditional periodization group did not improve significantly after the training week. There were no differences between groups. However, magnitude-based inference analysis showed likely beneficial and possibly beneficial effects for the HRV-guided group instead of the traditional periodization group in 40-min all-out time trial and peak power output, respectively. ***Conclusion:*** Daily training prescription based on HRV could result in a better performance enhancement than a traditional periodization in well-trained cyclists.

***Keywords:*** HRV, road cycling, periodization, endurance training, exercise performance

Road cycling is considered one of the hardest endurance sports in the world,[1] with high physiological demands during training and competition.[2–4] Professional cyclists often accumulate up to 90 days of competitive racing within a season,[1] which makes maintaining a healthy balance training/racing load and taking sufficient recovery time a challenge. Large gains in training status are generally achieved by prescribing high training loads followed by a minimal, but sufficient, recovery period.[5] Maintaining this balance is challenging as multiple factors such as training intensity, quality of sleep, nutrition, and psychological well-being might vary substantially on an individual basis.[6]

Monitoring individual responses to training is, therefore, an important key factor to prescribe to most effective training programs.[7] A promising variable that is able to reflect positive or negative training adaptation is cardiac autonomic regulation (CAR).[8] This is supported by Lamberts et al,[9] who showed that cyclists who adapted well to high intensity training (HIT) had a faster heart rate recovery (HRR) response than cyclists who did not responds well to the HIT. In general, a decreased training status is associated with a lower power output at the same submaximal heart rate and a slower HRR, whereas an increased training status is associated with an increased power output, the same submaximal heart rate, and a faster HRR.[10] Confusingly and counterintuitively, functional overreaching and acute fatigue are associated with increased power at the same submaximal heart rate and a faster HRR (similar to an improved training status), but in contrast to an improved training, status is associated with increased rate of perceived exertion (RPE) levels.[11,12] This counterintuitive response highlights the importance of monitoring properly, because without the RPE data, functional overreaching might be interpreted as an improvement in training status.

In addition to HRR, heart-rate variability (HRV), which focuses on the variability of successive R–R intervals,[13] also gained popularity in monitoring the training status of endurance athletes.[8,14–16] This tool enables the detection of fatigue status and assesses the adaptation to training. After HIT or a short-term overreached period, there is a decrease in the resting HRV values, reflecting the effect of the fatigue.[17,18] In addition, the increase of the performance after a training period (TW) is related to an increase in resting HRV.[8]

However promising the results of monitoring athletes, only a few studies[5,19,20] have looked at using CAR markers to prescribe or regulate exercise prescription. This HRV-guided training, also called day-to-day periodization, allows new possibilities for the training load prescription according to an athlete's status, the response to the training load, and the adaptation to training.[5] Although day-to-day periodization has been tested in endurance sports such as running[5,19,20] and cross-country skiing,[21] this new training prescription strategy has not been used in road cycling yet. Therefore, the purpose of this study was to determine the effect of an HRV-guided and a traditionally periodized training program on road cycling performance.

## Methods

### Subjects

Seventeen trained male cyclists with at least a personalized training history of 2 years were recruited from local clubs. The general characteristics of the participants are shown in Table 1, and the average cycling experience was 13 (10) years. Before taking part in the study, all participants were fully informed about the study and had to sign a written informed consent. The study was approved by

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the ethical committee of Miguel Hernandez University and was conducted to conform to the recommendations of the Declaration of Helsinki.

## Design

The study protocol was divided into 2 periods: (1) a baseline period (BW) and (2) a TW (see also Figure 1). The BW consisted of 4 weeks base training that functioned as a standardization period after which a baseline HRV measurement could be captured. After the BW, cyclists were randomly assigned to an HRV-guided training group (HRV-G, n = 9) or a traditional periodization training group (TRAD, n = 8). During the following 8 weeks, the cyclists trained based on the group they were allocated to. Cyclists in the HRV-G trained according to their HRV morning values, whereas TRAD cyclists trained based on a predetermined training program.

## HRV Versus TRAD Training

Participants maintained their weekly training volume during BW and TW. During evaluation week (EW), participants were encouraged to not perform any vigorous training session and to rest 24 hours prior to each test. During BW, the training intensity was increased gradually during the 3 first weeks and then reduced for the last week: 3 weeks of overload training and 1 recovery week

**Table 1 Participant Characteristics in PRE**

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

Abbreviations: BW, baseline week; HRV-G, heart-rate-variability-guided training group; PPO, peak power output; PRE, evaluation week before BW; TRAD, traditional training group; 40TT, power output during the 40-minute time trial; $VO_2max$, maximal oxygen uptake; VT, ventilatory threshold; WVT1, power output at VT1 intensity; WVT2, power output at VT2 intensity.

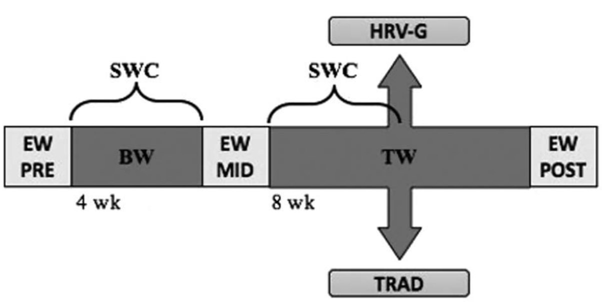


**Figure 1** — Experimental design. BW indicates baseline week; EW MID, evaluation week between BW and TW; EW PRE, evaluation week before BW; EW POST, evaluation week after TW; HRV-G, heart-rate-variability-guided training group; SWC, smallest worthwhile change; TRAD, traditional training group; TW, training week.

(3 : 1). BW served as a preparatory period for familiarization with training sessions and their intensities. Nevertheless, all participants were accustomed to high-intensity training prior to the beginning of the study. Training sessions and periodization of TRAD group are shown in Table 2, including low-intensity training (low; intensity < VT1), moderate-intesity training (mod; VT1–VT2), high-intensity training (high; ≥VT2), and high-intensity interval training (HIIT; >VT2).

For HRV-G, training in TW was prescribed according to participants' CAR status[5,19] following a decision-making schema modified from Kiviniemi et al[19] (Figure 2). Cyclists performed only 2 consecutive sessions of moderate- or high-intensity training and did not accumulate more than 2 consecutive days of rest. The HRV baseline was calculated as the smallest worthwhile change (SWC), explained below (HRV measurements). When $LnRMSSD_{7day\text{-}roll\text{-}avg}$ fell outside the SWC, training intensity changed from mod or high to low or rest. Typical training sessions are shown in Table 2; mod and high sessions were performed with a 45- to 60-minute warm-up and 20 minutes of cooling down. Figure 3 is an example of HRV fluctuations during the TW period.

There were 3 EWs: PRE (before BW), MID (between BW and TW), and POST (after TW). Each week of evaluation consisted of 2 testing sessions with a 48-hour recovery period. The first testing session included a maximal graded exercise test to obtain maximal oxygen uptake ($VO_2max$) and both ventilatory thresholds (VT1 and VT2) and their derived power outputs. In the second, 1 participant performed a 40-minute simulated time trial.

## Graded Exercise Test

$VO_2max$, VT1, and VT2 were calculated with a maximal graded exercise test. The test started with a 10-minute warm-up at 50 W, followed by an increase of 25 $W \cdot min^{-1}$ until exhaustion.[22] Participants performed all the tests on their own bikes, which were fitted on a Wahoo KICKR Power Trainer (Wahoo Fitness, Atlanta, GA).[23] The Wahoo KICKR Power Trainer was calibrated in each test during the 10-minute warm-up according to the manufacturer's recommendation. Participants were allowed to cycle at their own preferred cadence. The graded exercise test was terminated when a cyclist's cadence dropped more than 10 rounds per minute below his or her preferred cadence for more than 10 seconds. During the test, strong verbal encouragement was given in an attempt to make sure that cyclists performed to their maximal capacity.

Maximal oxygen consumption or $VO_2max$ was calculated as the highest 30-second $VO_2$ average. For the determination of VT1 and VT2, 15-second $O_2$ and $CO_2$ averages were used.[24] Respiratory gas exchange was measured using MasterScreen CPX (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

To measure endurance performance, cyclists performed a 40-minute all-out time trial (40TT) in the laboratory. Prior to the start of 40TT, a 10-minute warm-up was performed at a constant work of 50 W. Calibration of the graded exercise test was done as part of the warm-up. Cyclists were able to pace themselves throughout the test and change their gear ratio and pedal frequency as they preferred. Environmental conditions, such as temperature and humidity, were kept standard during all tests. Strong verbal

**Table 2 Periodization and Training Distribution for Both Groups During Weeks 1–5 and for TRAD During Weeks 7–14**

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

Abbreviations: BW, baseline week; EW MID, evaluation week between BW and TW; EW PRE, evaluation week before BW; EW POST, evaluation week after TW; GXT, graded exercise test; HIIT, high-intensity interval training; TRAD, traditional training group; TW, training week; VT1, first ventilatory threshold; VT2, second ventilatory threshold. Note: High-intensity, HIIT, and moderate-intensity sessions were performed with a 45- to 60-minute warm-up and 20 minutes of cooling down.



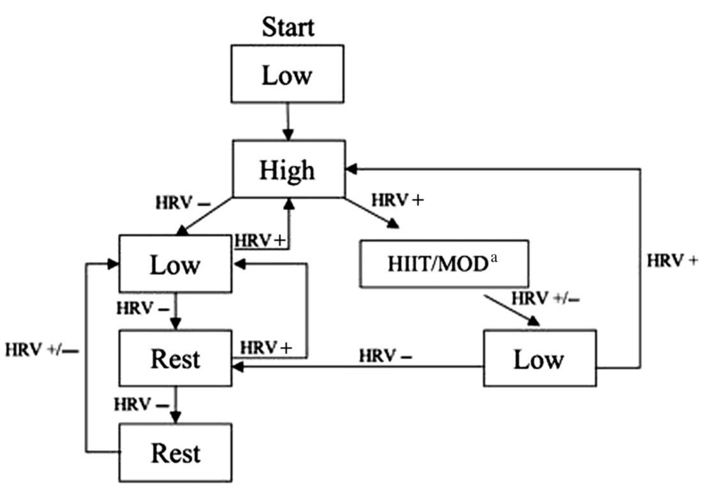


**Figure 2** — HRV-guided training schema. Modified from Kiviniemi et al.[19] When $LnRMSSD_{7day\text{-}roll\text{-}avg}$ remained inside SWC (+), high-intensity or moderate-intensity training sessions were prescribed. If $LnRMSSD_{7day\text{-}roll\text{-}avg}$ fell outside SWC (–), low intensity or rest were prescribed. HIIT indicates high-intensity interval training; HRV, heart-rate variability; $LnRMSSD_{7day\text{-}roll\text{-}avg}$, 7-day rolling average of the natural logarithm of the root-mean-squared differences of successive RR intervals; SWC, smallest worthwhile change. [a]HIIT/moderate sessions were alternated each week.

encouragement during the 40TT was given by researchers, and all data were blinded from the cyclists except for time. Cyclists were allowed to drink water ad libitum through the test.

Performance and endurance capacity was determined by the mean power output during the 40TT.

## HRV Measurements

All participants were instructed to measure their RR interval data at home every morning after waking up and emptying their urinary bladder, both during BW and TW periods. The HRV measurement was captured with a Polar H7 strap (Polar Team System; Polar Electro Oy, Kempele, Finland) and sent via app cloud service (Elite HRV app)[25] for analysis. HRV was measured in a supine position and over a 90-second period.[26] Cyclists were instructed to lie still and not perform any further activity during recordings. The HRV data were analyzed by Kubios HRV software (Finland Eastern University, Kuopio, Finland).[27] The first 30 seconds of the HRV measurement was discarded,[28] and a middle-level filter of artifact correction was applied to the rest of the data. 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.[4,29] The HRV data were transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution. A 7-day rolling average ($LnRMSSD_{7day\text{-}roll\text{-}avg}$)

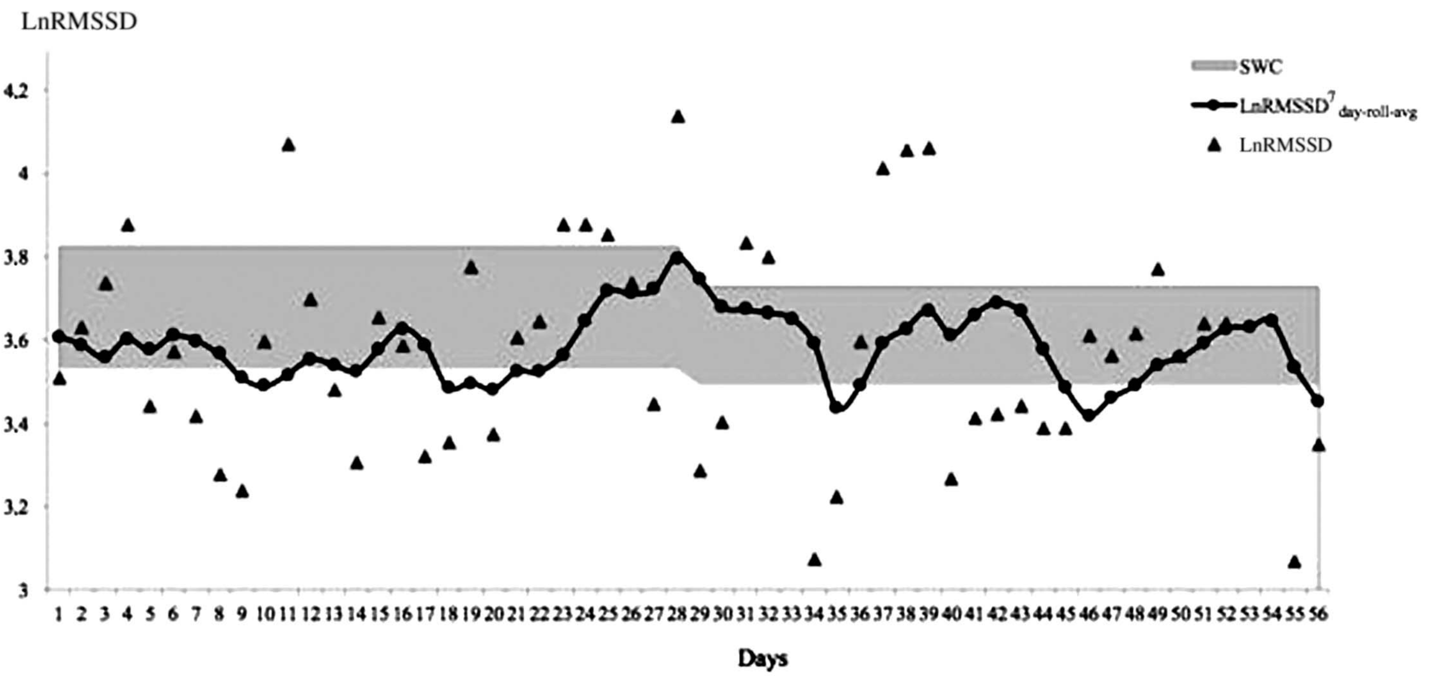


**Figure 3** — Example of individual response of HRV in an HRV-G cyclist. HRV-G indicates heart-rate-variability-guided training group; LnRMSSD, the natural logarithm of the root-mean-squared differences of successive RR intervals; $LnRMSSD_{7day\text{-}roll\text{-}avg}$, 7-day rolling average of LnRMSSD; SWC, smallest worthwhile change.



was calculated for the purpose of training prescription.[16] During BW, the SWC of LnRMSSD was calculated as mean ± 0.5 × SD, following the recommendations of Plews et al[16] and its usefulness for training prescription based on HRV measurements.[5] SWC was updated after the first 4 weeks of TW due to the relationship between CAR and the adaptation to training.[8] This SWC was used for the interpretation of changes in $LnRMSSD_{7day\text{-}roll\text{-}avg}$ and the consequent training prescription during the following 4 weeks.

## Statistical Analysis

The homogeneity of the data was tested with a Levene's test to ensure that all data were normally distributed. Based on the normal distribution, the data are presented as mean (SD). A repeated measure of analysis of variance followed by a Bonferroni post hoc test was performed to detect both within- and between-group changes in TW and to assess possible changes in all participants during BW. In addition, data were analyzed for practical significance using magnitude-based inferences both within- and between-groups comparison.[30] The smallest worthwhile difference in means in standardized (Cohen *d*) units was set at 0.2, representing the hypothetical smallest difference within and between groups. Furthermore, chances that any change was greater/similar/smaller than the other group were calculated (using effect size and its 90% confidence limits). Qualitative assessment of the magnitude of change was included according to the chances of benefit: 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%).[30] If the 90% confidence limits overlapped small positive or negative values, the magnitude of change was labeled as unclear. Results were analyzed with IBM SPSS Statistics (version 24.0; SPSS Inc, Chicago, IL) for the repeated measure of analysis of variance and Microsoft Excel 2016 (Microsoft Corp, Redmond, WA) for the magnitude-based inference analysis.

# Results

## Training

In BW, HRV-G and TRAD followed the same training prescription (3:1). There were no statistical differences in volume nor intensity distribution in either group during this period. The amount of time per week for both groups was 8 hours 17 minutes ± 2 hours 48 minutes for HRV-G and 8 hours 13 minutes ± 2 hours 42 minutes for TRAD. Furthermore, the percentages of time in the different intensity zones (below VT1/between VT1 and VT2/above VT2) were 61%/29%/10% and 60%/31%/9% for the HRV-G and TRAD group, respectively. During this period PPO ($P = .003$) and 40TT ($P < .0001$) improved, whereas $VO_2max$, WVT2, and WVT1 showed no changes.

In TW, the amount of time per week for both groups was 9 hours 18 minutes ± 2 hours 50 minutes for HRV-G and 8 hours 46 minutes ± 2 hours 47 minutes for TRAD. In addition, the percentages of time in the different intensity zones (below VT1/between VT1 and VT2/above VT2) were 66%/24%/10% and 64%/27%/9% for the HRV-G and TRAD group, respectively. The percentage of time between VT1 and VT2 was significantly higher in TRAD ($P = .04$; $d = 0.29$ [–0.05, 0.53]) than in HRV-G. The percentage of time expended below VT1 ($P = .21$; $d = 0.14$ [–0.20, 0.47]) and above VT2 ($P = .13$; $d = 0.13$ [–0.14, 0.53]) did not differ between groups.

## Within-Group Differences

In TW, within-group differences and practical significance are shown in Table 3. HRV-G improved PPO (5.1% [4.5%]; $P = .024$), WVT2 (13.9% [8.8%]; $P = .004$), and 40TT (7.3% [4.5%]; $P = .005$). $VO_2max$ and WVT1 remained similar, with no significant changes. Figure 4 represents individual changes in

**Table 3 Within-Group Differences in the Main Variables Measured**

| | HRV-G (n = 9) | | | | | TRAD (n = 8) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | MID | POST | Standardized change (90% confidence limits) | Chances | Qualitative assessment | MID | POST | Standardized change (90% confidence limits) | Chances | Qualitative assessment |
| $VO_2max$ | 56.34 (7.58) | 55.8 (8.18) | –0.09 (0.41; –0.58) | 16/51/34 | Unlikely beneficial | 54.30 (7.81) | 52.13 (6.78) | –0.22 (0.15; –0.59) | 3/42/55 | Very unlikely beneficial |
| PPO | 356.83 (39.74) | 374.28* (43.65) | 0.38 (0.58; 0.17) | 92/8/0 | Likely beneficial | 346.75 (16.73) | 351.50 (17.01) | 0.25 (1.11; –0.61) | 54/28/18 | Unclear |
| WVT2 | 275.00 (41.46) | 311.11** (37.73) | 0.94 (1.30; 0.59) | 100/0/0 | Most likely beneficial | 256.25 (17.68) | 281.25 (22.16) | 1.02 (1.77; 0.27) | 96/3/1 | Very likely beneficial |
| WVT1 | 191.67 (27.95) | 200.00 (25.01) | 0.32 (0.62; 0.01) | 75/24/1 | Possibly beneficial | 175.00 (23.15) | 178.13 (28.15) | 0.07 (0.42; –0.29) | 29/64/7 | Unclear |
| 40TT | 243.11 (41.73) | 260.78** (44.76) | 0.33 (0.45; 0.21) | 96/4/0 | Very likely beneficial | 214.42 (32.36) | 223.13 (36.15) | 0.21 (0.40; 0.03) | 53/47/0 | Possibly beneficial |

Abbreviations: HRV-G, heart-rate-variability-guided training group; MID, evaluation week between baseline weeks and training weeks; POST, evaluation week after training weeks; PPO, peak power output; TRAD, traditional training group; 40TT, power output during the 40-minute time trial; $VO_2max$, maximal oxygen uptake; VT, ventilatory threshold; WVT1, power output at VT1 intensity; WVT2, power output at VT2 intensity.

endurance performance (40TT) for both groups. Only 1 participant in HRV-G decreased the power output during 40TT in POST (−1%), whereas in TRAD, 2 subjects decreased the power output during 40TT, by −2% and −5%. In addition, HRV-G presents the best individual increments in performance.

## Between-Groups Differences

For all the variables measured during EW ($VO_2$max, PPO, WVT1, WVT2, and 40TT), there were no differences between groups in PRE, MID, and POST. Between-group practical significance and qualitative assessment are shown in Figure 5. This comparison showed that HRV-G produced greater increases in PPO, WVT2, and 40TT.

In addition, there were significant differences ($P = .0006$) in the relative change of LnRMSSD between groups (Figure 6). There was lower variation for HRV-G group (0.85% [3.21%]) than TRAD (−2.02% [5.21%]).

## Discussion

This study set out with the aim of comparing the effect of a day-to-day training prescription based on HRV and a traditional training program. The major finding was that HRV-G led to substantial greater increase in PPO, WVT2, and 40TT than TRAD shown by a possibly beneficial effect for PPO and WVT2 and a likely beneficial effect for 40TT (Figure 5). Furthermore, power output in the main variables showed greater magnitude of change in HRV-G, suggesting positive effects for this group. To the best of our knowledge, this is the first study to apply a training program based on HRV in road cycling.

The time expended between VT1 and VT2 was lower in HRV-G than in TRAD. Consequently, the percentage of time below VT1 was higher (but not significant) in HRV-G, whereas time expended upper VT2 remained similar between groups. The distribution in HRV-G is in accordance with the report by da Silva et al,[31] which found a lower proportion of moderate intensity for the HRV-G.

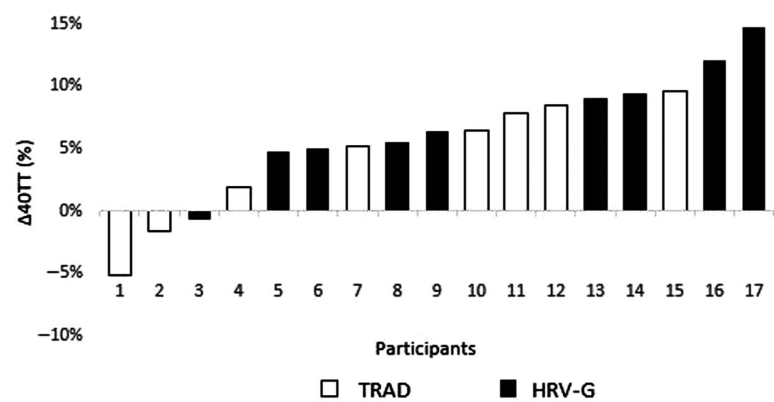


**Figure 4** — Individual differences in changes in performance for both groups. 40TT indicates power output during the 40-minute time trial; HRV-G, heart-rate-variability-guided training group; TRAD, traditional training group.

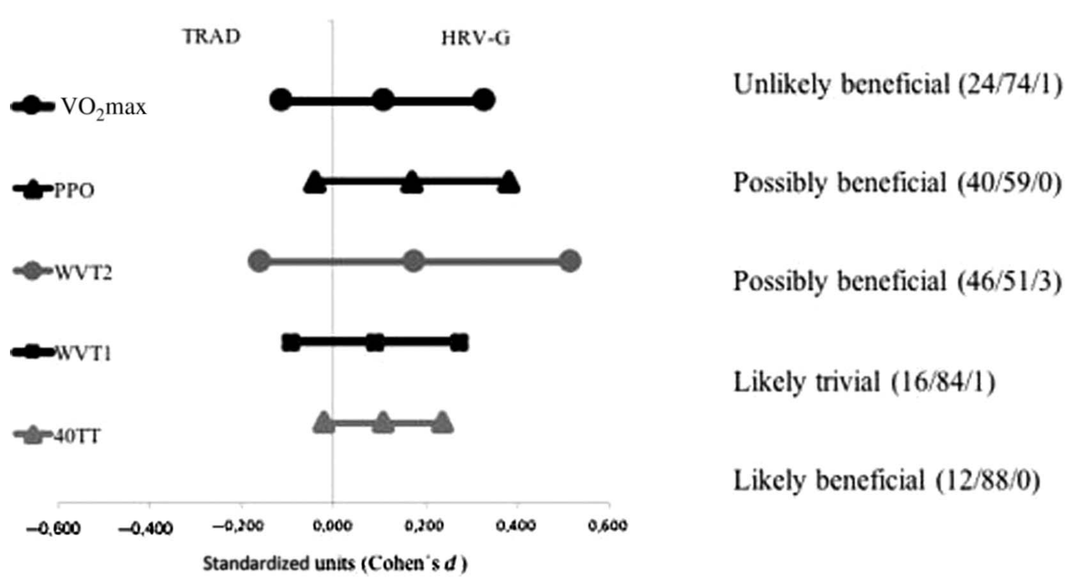


**Figure 5** — Between-groups changes in performance. 40TT indicates power output during the 40-minute time trial; HRV-G, heart-rate-variability-guided training group; PPO, peak power output; TRAD, traditional training group; $VO_2$max, maximal oxygen uptake; VT, ventilatory threshold; WVT1, power output at VT1 intensity; WVT2, power output at VT2 intensity.

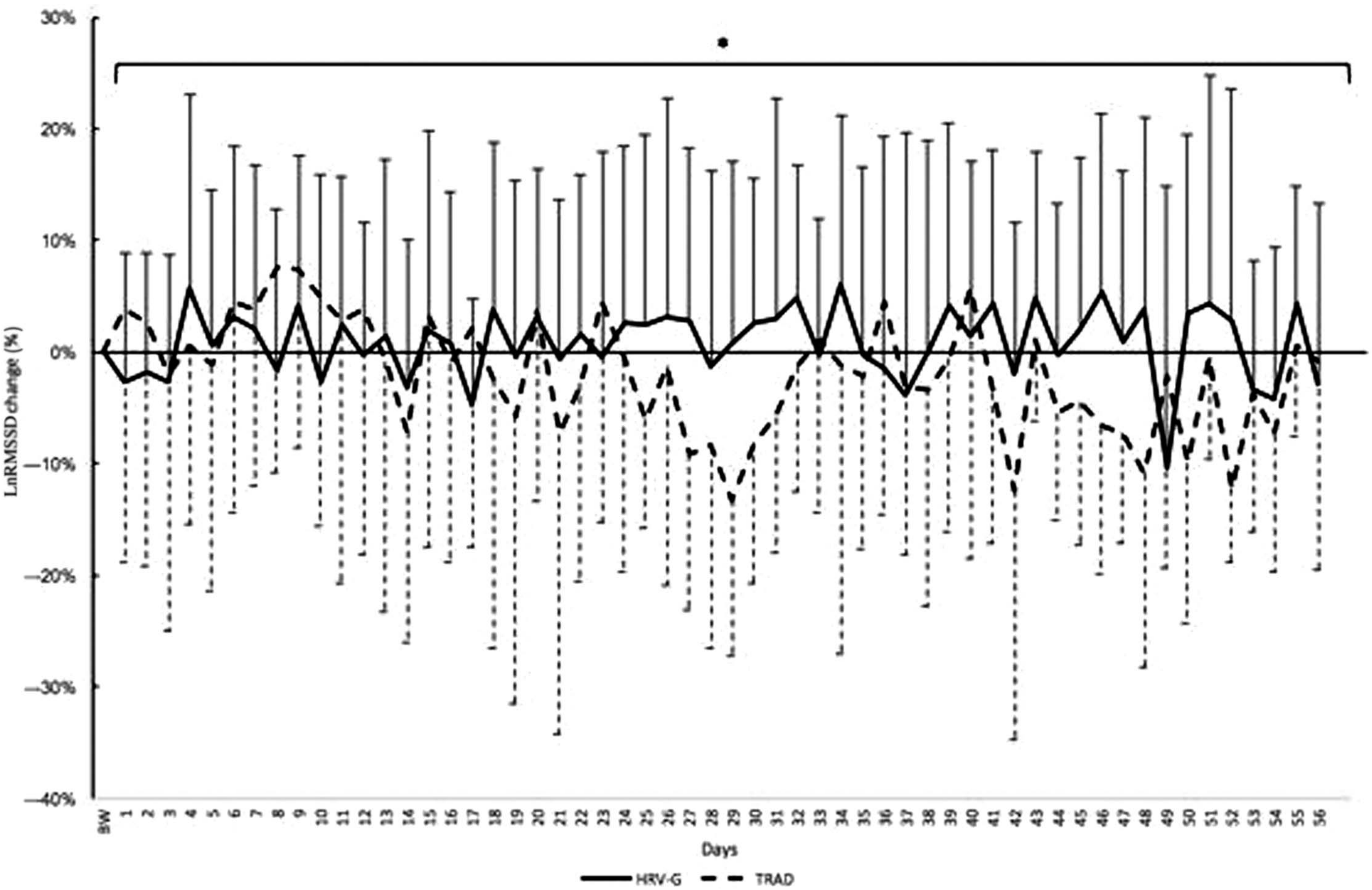


**Figure 6** — LnRMSSD change (%) during TW period for both the HRV-G and the TRAD groups. BW indicates baseline week; HRV-G, heart-rate-variability-guided training group; LnRMSSD, the natural logarithm of the root-mean-squared differences of successive RR intervals; TRAD, traditional training group; TW, training week. **P* < .001 for difference of change in LnRMSSD between groups.



Regarding these differences, training prescription based on resting morning values of HRV could lead to a lower proportion of moderate and a greater low- and high-intensity training. This distribution has demonstrated greater performance enhancement in well-trained and elite endurance athletes.[32] Thus, the decision-making schema (Figure 2) and the SWC (Figure 3) could provide a distribution of training sessions that favors performance improvement. $VO_2$max is considered one of the factors that determines performance in endurance sports.[33] $VO_2$max did not change in either group and presents unlikely beneficial effects. The results differ from some studies reporting beneficial changes in $VO_2$max for the HRV-G.[5,19] However, these studies were performed with untrained[19] and recreational runners,[5,34] and $VO_2$max is more susceptible to change due to the adaptation to training in this population. Thus, the differences in the results could be as a consequence of the participant's high performance level because the trainability of this parameter is limited in well-trained and elite endurance athletes.[35]

PPO is a parameter that indicates the aerobic potential of cyclists.[36] In HRV-G, PPO increased significantly and presented possible beneficial effects. Furthermore, HRV-G presents a greater magnitude of change than TRAD (Table 3). These results are in accordance with other studies[5,19,34] which found similar increases in maximal aerobic velocity when applying the training guided by HRV in middle-distance running, such as road cycling an endurance sport with similar demands. It has been suggested that HIT could improve PPO.[37] Although training intensity over anaerobic threshold was similar for both groups, PPO increased more in HRV-G. In HRV-G, only HIT was prescribed when the $LnRMSSD_{7day\text{-}roll\text{-}avg}$ values were within the SWC. Our hypothesis for this greater adaptation to training for HRV-G is in line with the idea of performing HIT, when the athlete is in optimal conditions to perform it. Therefore, these differences in PPO changes may be due to a better timing in the programming of HIT.

The competitive situations that have a major impact on the result of a race are mountain passes and time trials. Although the competition in road cycling is performed around the aerobic threshold in mass-start races,[38,39] the mountain passes are performed around anaerobic threshold.[40] Thus, WVT2 is one of the performance determinants in road cycling. WVT2 improved significantly in HRV-G but not in TRAD. However, the magnitude of change for both groups (Table 3) showed a most likely beneficial result for HRV-G and very likely beneficial result for TRAD. These results were in line with those reported by the literature,[5,19,34] showing greater effects for HRV-G (Figure 5). In addition, the percentage of cyclists who improved WVT2 was 89% for HRV-G and 63% for TRAD. These results support the idea that the homogenization of traditional training programs produces different levels of response and adaptation of the athletes, preventing the individualization and adjustment of the training load, which would be obtained using the HRV as a tool to control adaptation.[6] Therefore, tools such as HRV will allow us to take the principle of individualization of the load a step further.

Regarding WVT1, this parameter did not change significantly in either group, and it presents a trivial between-group effect (Figure 5). In addition, the results showed possibly beneficial effects for HRV-G and unclear effects for TRAD (Table 3). These results differ from other results[34] that reported significant increases for both the group that performed training based on HRV and the predetermined training group. However, the study by Nuuttila et al[34] implemented resistance training in their methodology, whereas our study included only endurance training. It has been previously reported that concurrent training of strength and endurance could lead to increases in aerobic capacity and performance.[41,42] This fact might explain the different outcome in this variable, leading to the absence of significant changes in our study. The qualitative assessment based on the effect size showed possible beneficial effects for the change in WVT1 for HRV-G, whereas it showed unclear results for TRAD. In this case, we cannot compare our result with those previously reported[34] because previous studies did not perform this analysis.

Performance, measured through 40TT, increased in HRV-G but not in TRAD (Table 3). In addition, HRV-G leads to substantial greater increase in this variable with higher magnitude of change. The finding mirrors those of the previous studies[5,31] that have examined the effect of a day-to-day training prescription based on HRV compared with a traditional training prescription. In this case, power output during 40TT was between WVT1 and WVT2 (Table 3), whereas the percentage of time expended at moderate intensity (between VT1 and VT2) was significantly lower the in HRV-G group. Therefore, the greater improvements in HRV-G may be due to a better periodization of the different type of training sessions. Another explanation for this result could be that the greater improvement in PPO and WVT2 also caused the improvement in performance in 40TT due to the increase of aerobic performance.

Daily variation of HRV was significantly greater for TRAD instead of HRV-G (Figure 6). In addition, the SD was also greater for the TRAD group. This result suggests that maintaining HRV values within an optimal range during the training process could result in greater increases in performance. This finding is in accordance with another study performed in cross-country skiing,[21] suggesting lower variations in daily HRV measurements and higher increases in performance for an HRV-guided training group.

This study has some limitations that must be highlighted: (1) Training was performed by the cyclists without direct supervision during the training sessions. However, cyclists uploaded their data immediately after training sessions were performed and were supervised on a daily basis. Road cycling is a sport that is performed outdoors, so it is complex to perform the training sessions with the presence of the research group. (2) HRV measurements were performed at home and without direct supervision. However, all data were revised every morning to detect possible mistakes in the measurements. Furthermore, participants were carefully instructed during PRE. This evaluation week also served as a familiarization period with all procedures. In addition, it is impractical for cyclists to come to the laboratory to evaluate HRV morning values every day during the study period. (3) The determination of SWC was calculated with the same criterion for all the participants when HRV presented a high variation between subjects.[14] More research is necessary to develop new methodologies to establish an individualized SWC that could be more accurate than a fixed calculation of this range.

## Conclusion

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

## Practical Applications

This study showed greater improvements for a day-to-day prescription than a predefined training program. To the best of our knowledge, a day-to-day training prescription based on daily HRV measurements had not been tested in this sport yet. In endurance sports with high physiological demands, such as road cycling, the timing in the prescription of training load is a key factor to optimize the increases in performance. This study reflects how to optimize the training process based on the status of the cyclists and their response to the previous training sessions. Furthermore, this study has been conducted with a smartphone application and a commercial Bluetooth strap to perform the measurements, highlighting the accessibility of the HRV measurements for field conditions. In addition, ultra-short-HRV recordings have been used to evaluate fatigue and response to training,[43,44] but not in day-to-day training prescription. This study provides support for the possibilities of these recordings, which has great practical applications in the field. Previous studies of day-to-day training prescription used ≥4-minute HRV recordings, whereas in this study, the measurements were performed with ultra-short-HRV recordings.

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