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ORIGINAL ARTICLE

No evidence of association between HRV and training volume in a pool of professional athletes before, during, and after the first COVID-19 lockdown

Aucune preuve d'association entre la VFC et le volume d'entraînement dans un groupe d'athlètes professionnels avant, pendant et après le premier confinement lié à la COVID-19

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KEYWORDS
Heart rate variability;
Cycling;
COVID-19;
Professional cyclists

Summary
Objectives. — The COVID-19 crisis also affected elite sport severely, as elite athletes either stopped or drastically reduced their training regimen due to the lack of competitions and the mandatory lockdown. The aim of this study was to test whether heart rate variability was a reliable index of training load, which was dramatically altered due to the mandatory lockdown that occurred as a consequence of the COVID-19.
Equipment and methods. — Training (volume and intensity) and heart rate variability of sixteen professional male ($n = 8$; body mass index $= 22.2 \pm 2.0$) and female cyclists ($n = 8$; body mass index $= 20.3 \pm 1.1$) before (4 weeks), during (7 weeks), and after (4 weeks) the mandatory lockdown in Spain were monitored.

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Results. — Individual analyses showed that the mandatory lockdown caused reliable reductions in training volume in 13 subjects (—96 to —7% reductions in minutes), that were followed by an increase after the lockdown in all subjects (5 to 270%). In contrast, changes in training load were not homogenous across individuals. Moreover, such changes were not matched by comparable variations in heart rate variability. A mixed model of the heart rate variability as a function of training volume and intensity revealed no significant modulation by these two variables, and subject specific effects on the slope. In this study, we did not find evidence of association between heart rate variability and training load and/or intensity as many previous reports have suggested, even if training conditions changed dramatically overnight.

MOTS CLÉS
Variabilité de la fréquence cardiaque ;
Vélo ;
COVID-19 ;
Cyclistes professionnels

Résumé
Objectifs. — La crise du COVID-19 a également gravement affecté le sport d'élite, car les athlètes d'élite ont arrêté ou réduit considérablement leur programme d'entraînement en raison du manque de compétitions et du confinement obligatoire. Le but de cette étude était de tester si la variabilité de la fréquence cardiaque était un indice fiable de la charge d'entraînement, qui a été considérablement modifiée en raison du confinement obligatoire qui s'est produit à la suite du COVID-19.
Matériel et méthodes. — Entraînement (volume et intensité) et variabilité de la fréquence cardiaque de seize cyclistes professionnels hommes ($n = 8$; indice de masse corporelle = 22,2 ± 2,0) et femmes cyclistes ($n = 8$; indice de masse corporelle = 20,3 ± 1,1) avant (4 semaines), pendant (7 semaines) et après (4 semaines) le confinement obligatoire en Espagne ont été surveillés.
Résultats. — Les analyses individuelles ont montré que le confinement obligatoire a entraîné des réductions fiables du volume d'entraînement chez 13 sujets (—96 à —7 % de réduction des minutes), qui ont été suivies d'une augmentation après le confinement chez tous les sujets (5 à 270 %). En revanche, les changements dans la charge d'entraînement n'étaient pas homogènes d'un individu à l'autre. De plus, ces changements n'étaient pas accompagnés de variations comparables de la variabilité de la fréquence cardiaque. Un modèle mixte de la variabilité de la fréquence cardiaque en fonction du volume et de l'intensité de l'entraînement n'a révélé aucune modulation significative par ces deux variables et des effets spécifiques au sujet sur la pente. Dans cette étude, nous n'avons trouvé aucune preuve d'association entre la variabilité de la fréquence cardiaque et la charge et/ou l'intensité d'entraînement, comme l'ont suggéré de nombreux rapports précédents, même si les conditions d'entraînement ont radicalement changé du jour au lendemain.

1. Introduction

At the beginning of 2020, a coronavirus named SARS-CoV-2 spread worldwide and, as a consequence, the majority of the world population were totally or partially confined in an attempt to reduce the expansion of the virus [1,2]. The COVID-19 crisis also affected elite sport severely, as major international events were postponed (e.g., the 2020 Tokyo Olympics will take place in 2021) or cancelled [3]. Moreover, elite athletes either stopped or drastically reduced their training regimen due to the lack of competitions and the mandatory lockdown [4]. This sudden change in the training conditions had an impact on the group of professional cyclists that our research group was monitoring since January 2020, allowing us to study the consequences of the lockdown in terms of training load and heart rate variability (HRV). This paper contains a full description of the individual and group variations in these training parameters.

The carefully monitoring of training and athletes' status is one of the most important tasks to favour a successful adaptation process. In this regard, HRV, which focuses on the variability of successive R-R intervals [5], has been proposed as a promising variable to evaluate positive or negative adaptation to training [6], fatigue status [7] and the acute response to training [8]. HRV evaluates non-invasive cardiac autonomic regulation and its measurement has been optimized (e.g., reducing the recording duration [9]) carrying out recordings through smartphone applications [10,11] allowing the implementation of daily HRV recording. Decrements in HRV have been related to an increase of training load [12] and high-fatigue status [13], while increases in HRV have been related to positive adaptations to training [6]. As HRV measurement was part of the monitoring process of a group of professional cyclists during their regular season, the mandatory confinement provided the opportunity to describe the HRV variations that may have taken place as a consequence of the large change in training conditions.

Here, as noted above, and in agreement with other research [14], we expected an abrupt reduction in training volume during the lockdown. In contrast, the indoor smart trainers would allow cyclists to follow the training regime in terms of intensity. Finally, if HRV is a robust index of training load and adaptation monitoring, as suggested by previous work [15], one should expect a reliable increase in HRV during the confinement as a consequence of the reduction in physical stress, and a concomitant decrease of HRV with the return to regular training after the lockdown.

2. Methodology

2.1. Subjects

A group of sixteen ($n = 16$) male ($n = 8$; BMI = 22.2 ± 2.0) and female ($n = 8$; BMI = 20.3 ± 1.1) professional cyclists were included in this report. They were all previously involved in a follow-up process of their training by their professional cycling team. All cyclists were fully informed about the purpose of this research and had to sign a written informed consent. The cyclists were healthy and remained free of injury during the duration of the study. The research followed the principles of the declaration of Helsinki and the study was approved by the Ethical Committee of Miguel Hernandez University of Elche, Spain.

2.2. Design

The data were divided and analysed by weeks: week 1 to 4 (pre-lockdown), 5 to 11 (lockdown) and 12 to 15 (post-lockdown). During pre and post, the cyclists maintained their individualized training program while during the lockdown, coaches adapted the cyclists' training to an indoor training cycling regime. To avoid the negative effects of detraining [16—18], the cyclists were encouraged by their technical staff to maintain a certain level of physical activity during the lockdown period. This was achieved mainly through the use of indoor trainers that simulate the specific training conditions. To adapt to the unexpected and sudden lockdown, albeit maintaining the individualization, the coaches first reduced training volume. This happened since the usual training was modified by indoor training. Indoor training does not allow training volume as high as outdoor training due to several factors such as less ventilation or the absence of non-pedalling phases. Training intensity was prescribed individually by the coaches and measured through power output. In addition, as a part of their monitoring regime, the cyclists recorded their HRV daily.

3. Methods

As a part of their usual schedule, all the cyclists conducted a graded exercise test (GXT) during the pre-season to determine maximal oxygen uptake (VO_2max), the first and second ventilatory thresholds (VT1 and VT2, respectively) and the power output associated to these points (PPO, PO_{VT1} and PO_{VT2}, respectively) [19].

The training sessions were continuously monitored with a Garmin 820 (Garmin Ltd, Southampton, United Kingdom) that recorded training volume and intensity. Training intensity was monitored and divided into three intensity-training zones [20]: zone 1 (low intensity training: time expended below VT1), zone 2 (moderate intensity: time expended between VT1 and VT2) and zone 3 (high intensity: time expended above VT2). Training data was analysed daily using specific training software that includes a cloud service (TrainingPeaks, Boulder, USA). Subjects used their own bikes, and output and cadence were monitored continuously throughout all workouts using a mobile powermeter (Quarq, Spearfish, SD, USA) [21]. In addition, power output recordings were divided into ranges of 0.5 W/kg^{-1}, from 0 W/kg^{-1} to 10 W/kg^{-1} to assess the power distribution during the different periods (pre, lockdown and post).

Training load was calculated using the Training Stress Score (TSS) [22], which was computed using the following equation:

$$TSS = ((t \cdot NP \cdot IF) / (FTP \cdot 3600)) \cdot 100$$

Where t is the duration of the training in seconds, NP is the normalized power attained during the training, and IF (intensity factor) is the ratio between the NP and the functional threshold power (FTP), i.e., 95% of the highest 20-minute mean PO obtained during the training sessions, tests and competitions of the preceding four weeks [23]. The TSS metric was expressed in arbitrary units.

For HRV measurements, all participants were instructed to record their R-R interval data upon waking up and emptying their urinary bladder. The HRV measurements were captured with the HRV4training smartphone application through plethysmography [11]. HRV was recorded in a seated position and over a 90 s period of time [24]. Cyclists were instructed to remain seated and to avoid any activity during the recordings. The first 30 s were discarded for signal stabilization and the last 60 s of the HRV measurement were captured for the analysis [24]. Erroneous data were discarded from any recording. The application was designed to inform the user whether the measurement was valid or not. Periods of high noise, artifact and ectopic beats were identified and discarded. In cases where the HRV data attained were inappropriate due to user error (e.g. movement of the finger over the camera) or insufficient data, the subject would be informed and the measurement would be discarded. The subject would then be asked to make another recording until it was deemed successful by the application. The root mean squared differences of successive RR intervals (RMSSD) was chosen as the vagal index, based on its greater suitability and reliability than other indexes. The HRV data was transformed by taking the natural logarithm (LnRMSSD) to allow parametric statistical comparisons that assume a normal distribution. A 7-day rolling average of LnRMSSD was calculated (LnRMSSD_roll7d) to analyse cardiac autonomic regulation adaptation [25].

3.1. Statistical analysis

The variations in training volume (in seconds), TSS and HRV (lnRMSSD) averaged over each period for all the subjects were assessed by a pairwise post-hoc test for multiple comparisons of rank sums (Durbin-Conover) performed in ggstatplot [26].

To test the association between HR, training volume (Training) and TSS we used a mixed model with training volume, TSS, and consecutive days as predictors, and interactions between Day and Training and Day and TSS.

The HRV measure refers to the one taken the day after the training. The models were estimated with the package's stat (R version 4.0.3) and lme4 (version 1.1.26).

$$\mathrm{HRV}_i \sim N\left(\mu, \sigma^2\right)$$

$$\mu = \alpha_{j[i],k[i]} + \beta_{1j[i],k[i]}(\mathrm{Training}) + \beta_{2j[i],k[i]}(\mathrm{Day}) + \beta_{3j[i],k[i]}(\mathrm{TSS}) + \beta_4(\mathrm{Day} \times \mathrm{Training}) + \beta_5(\mathrm{Day} \times \mathrm{TSS})$$

$$\begin{pmatrix} \alpha_j \\ \beta_{1j} \\ \beta_{2j} \\ \beta_{3j} \end{pmatrix} \sim N\left(\begin{pmatrix} \mu_{\alpha_j} \\ \mu_{\beta_{1j}} \\ \mu_{\beta_{2j}} \\ \mu_{\beta_{3j}} \end{pmatrix}, \begin{pmatrix} \sigma^2_{\alpha_j} & \rho_{\alpha_j\beta_{1j}} & \rho_{\alpha_j\beta_{2j}} & \rho_{\alpha_j\beta_{3j}} \\ \rho_{\beta_{1j}\alpha_j} & \sigma^2_{\beta_{1j}} & \rho_{\beta_{1j}\beta_{2j}} & \rho_{\beta_{1j}\beta_{3j}} \\ \rho_{\beta_{2j}\alpha_j} & \rho_{\beta_{2j}\beta_{1j}} & \sigma^2_{\beta_{2j}} & \rho_{\beta_{2j}\beta_{3j}} \\ \rho_{\beta_{3j}\alpha_j} & \rho_{\beta_{3j}\beta_{1j}} & \rho_{\beta_{3j}\beta_{2j}} & \sigma^2_{\beta_{3j}} \end{pmatrix}\right), \text{ for Period:Subject j} = 1, \ldots, 3$$

$$\begin{pmatrix} \alpha_k \\ \beta_{1k} \\ \beta_{2k} \\ \beta_{3k} \end{pmatrix} \sim N\left(\begin{pmatrix} \mu_{\alpha_k} \\ \mu_{\beta_{1k}} \\ \mu_{\beta_{2k}} \\ \mu_{\beta_{3k}} \end{pmatrix}, \begin{pmatrix} \sigma^2_{\alpha_k} & \rho_{\alpha_k\beta_{1k}} & \rho_{\alpha_k\beta_{2k}} & \rho_{\alpha_k\beta_{3k}} \\ \rho_{\beta_{1k}\alpha_k} & \sigma^2_{\beta_{1k}} & \rho_{\beta_{1k}\beta_{2k}} & \rho_{\beta_{1k}\beta_{3k}} \\ \rho_{\beta_{2k}\alpha_k} & \rho_{\beta_{2k}\beta_{1k}} & \sigma^2_{\beta_{2k}} & \rho_{\beta_{2k}\beta_{3k}} \\ \rho_{\beta_{3k}\alpha_k} & \rho_{\beta_{3k}\beta_{1k}} & \rho_{\beta_{3k}\beta_{2k}} & \sigma^2_{\beta_{3k}} \end{pmatrix}\right), \text{ for Subject k} = 1, \ldots, 15$$

4. Results

4.1. Within group changes

Fig. 1 reports the average TSS, the average training volume (in seconds), and the average HRV (lnRMSSD) for all the subjects, across the three periods, as well as the results of the Durbin-Conover test. Table 1 shows the week-by-week individual changes (%) of the mentioned variables. In addition, Fig. 2 shows the heterogeneous changes among cyclists at the pre, during and post-lockdown periods in both male (Fig. 2A) and female (Fig. 2B).

Fig. 3 reports the slopes per each period for each subject, and Fig. 4 reports the random effects.

4.2. Model results

The model results are displayed in Table 2.

5. Discussion

This study aimed to test the association between HRV and training load when the latter was strongly modulated in a group of professional male and female cyclists who had a dramatic change in their training regime due to the mandatory lockdown caused by the COVID-19 global pandemic during 2020.

The overall decrease in training volume is particularly relevant because professional cyclists typically cycle between 2 and 6 hours per day in outdoor conditions, while indoor training is carried out in specific situations (e.g. bad weather) and the training duration is often shorter. Nevertheless, indoor training was the only option to maintain a certain level of physical activity during the mandatory lockdown. In contrast to volume, the week-by-week individual training intensity distribution (Table 1) showed a high inter-subject heterogeneity. Furthermore, there was not a consistent increase in high intensity training during the weeks of lockdown in any cyclist. Thus, it seems that the lockdown did not produce a homogeneous change in the training intensity (which did happen with the training volume), suggesting that cyclists were able to maintain their individualised training program.

The crucial result of our study was that HRV individual response did not seem to be related to changes in training volume and/or intensity. This heterogenous response in our group of elite cyclists could be the consequence of the numerous variables that may influence HRV. Indeed, the lockdown likely affected mood, level of stress, sleep patterns, food habits, all factors that have been related to HRV [27]. Subjects were indeed the greatest source of variability of the association between HRV and training (both as volume in seconds and TSS); see Fig. 4. The period (pre-lockdown, lockdown, and post-lockdown) had a limited to negligible effect in interaction with the subjects. It is worth to stress that we did not measure all possible factors which could modulate the HRV.

Our result contrasts with earlier findings in well-trained cyclists that showed a relationship between changes in training load and HRV [12]. Our results are nonetheless

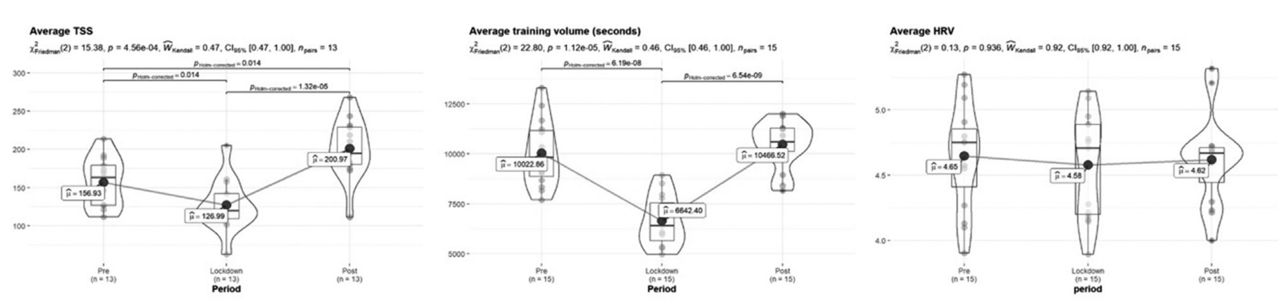

Figure 1 Average TSS (left), Training volume (center) and HRV (right) for all the subjects across the three periods. Pairwise differences between periods are assessed by means of the Durbin-Conover test.

Table 1 Individual changes (%) from previous week. No data are reported when no time was expended at a given intensity during the week.

			Pre				Lock							Post			
Subject	Gender	HRV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	M		0%	3%	1%	0%	−2%	−5%	4%	3%	−3%	3%	−4%	1%	7%	−2%	0%
2	M		0%	−2%	−4%	8%	−1%	0%	1%	1%	−3%	1%	2%	−1%	−4%	4%	1%
3	M		0%	1%	−5%	2%	3%	3%	−5%	6%	−11%	7%	−1%	11%	−12%	−4%	10%
4	M		0%	−4%	9%	−7%	−2%	2%	4%	−2%	−6%	2%	3%	4%	−1%	−4%	3%
5	M		0%	4%	−2%	−7%	3%	2%	6%	−5%	1%	0%	−3%	6%	−5%	2%	3%
6	M		0%	−20%	7%	2%	−1%	−1%	11%	−7%	−10%	6%	6%	0%	−10%	4%	−1%
7	M		0%	2%	−7%	5%	2%	−2%	0%	4%	0%	−3%	1%	0%	−5%	4%	−3%
8	M		0%	1%	−9%	−3%	9%	−4%	−4%	3%	2%	−12%	4%	7%	0%	−2%	0%
9	F		0%	−7%	2%	−2%	10%	2%	0%	2%	−2%	−2%	1%	−12%	11%	0%	−7%
10	F		0%	3%	−5%	2%	−5%	1%	−4%	0%	−12%	[a]	[a]	[a]	[a]	−2%	−2%
11	F		0%	−4%	−1%	−5%	3%	4%	−2%	−1%	−5%	8%	0%	−3%	−3%	4%	1%
12	F		0%	−5%	−2%	2%	−1%	5%	−4%	−2%	1%	−3%	4%	3%	0%	−1%	−1%
13	F		0%	4%	−1%	0%	0%	2%	1%	0%	−2%	−1%	1%	0%	−5%	4%	−3%
14	F		0%	3%	−4%	1%	−1%	6%	1%	−1%	−8%	0%	4%	−7%	8%	−3%	−5%
15	F		0%	0%	−10%	6%	−20%	8%	2%	8%	5%	2%	1%	0%	−1%	4%	−1%
		VOL															
1	M		0%	72%	−12%	−23%	−7%	13%	11%	−30%	19%	−82%	−100%	100%	23%	20%	11%
2	M		0%	−27%	−20%	27%	−39%	35%	4%	−3%	−29%	−4%	−4%	80%	16%	9%	−13%
3	M		0%	60%	−7%	7%	−6%	−9%	7%	−1%	−13%	−4%	26%	12%	−1%	7%	−13%
4	M		0%	71%	−28%	−19%	49%	−58%	22%	−46%	81%	8%	21%	138%	−60%	177%	5%
5	M		0%	18%	−1%	−28%	−8%	13%	22%	−9%	−47%	78%	−6%	64%	16%	−1%	10%
6	M		0%	−27%	58%	12%	−59%	7%	−23%	−52%	75%	−71%	236%	270%	−21%	35%	3%
7	M		0%	30%	−41%	39%	−60%	32%	47%	5%	−8%	26%	−9%	19%	−10%	35%	27%
8	M		0%	−66%	−51%	342%	−58%	−100%	100%	11%	28%	−9%	26%	68%	5%	−12%	−20%
9	F		0%	−6%	−28%	55%	−96%	−100%	100%	24%	−7%	−19%	9%	51%	36%	−6%	−12%
10	F		0%	28%	−22%	16%	−70%	102%	−36%	24%	−8%	−4%	32%	5%	50%	16%	−1%
11	F		0%	−14%	19%	−12%	−55%	52%	−2%	−54%	46%	81%	−36%	54%	−2%	20%	−18%
12	F		0%	−13%	−44%	14%	8%	35%	7%	−8%	−41%	62%	−19%	19%	50%	7%	−47%
13	F		0%	41%	−13%	11%	−38%	23%	−22%	20%	3%	−8%	37%	34%	3%	−28%	39%
14	F		0%	−26%	−13%	30%	−39%	6%	25%	−9%	−23%	18%	7%	71%	8%	−3%	−4%
15	F		0%	−28%	−8%	26%	−8%	−46%	7%	8%	−36%	42%	15%	86%	−26%	25%	−14%
		TSS															
1	M		0%	121%	−18%	−31%	19%	18%	25%	−35%	−1%	−89%	−100%	100%	28%	20%	18%
2	M		0%	150%	−37%	52%	−16%	28%	23%	3%	−33%	−11%	12%	37%	6%	−15%	20%
3	M		0%	65%	36%	3%	−7%	−27%	34%	3%	−1%	−17%	17%	−6%	10%	0%	−5%
4	M		0%	54%	−43%	10%	65%	−58%	79%	−52%	73%	−7%	15%	85%	−71%	372%	26%
5	M		0%	192%	−62%	−6%	16%	−20%	132%	−23%	−52%	72%	−27%	18%	47%	14%	−23%
6	M		0%	30%	36%	3%	17%	−15%	18%	−28%	7%	−9%	16%	−12%	35%	−19%	0%
7	M		0%	55%	−53%	36%	−46%	61%	32%	14%	−26%	30%	−55%	87%	10%	41%	22%
8	M		0%	−88%	−43%	736%	−40%	−100%	100%	1%	18%	−18%	−32%	176%	6%	−18%	−11%
9	F		0%	−19%	37%	−15%	−72%	60%	132%	−29%	−23%	−7%	46%	19%	50%	−3%	6%
10	F		0%	0%	0%	0%	0%	91%	−67%	65%	15%	−100%	0%	100%	948%	98%	39%
11	F		0%	−11%	−45%	8%	45%	40%	2%	−7%	−49%	64%	−21%	32%	40%	−1%	−43%
12	F		0%	93%	−38%	61%	−37%	13%	11%	20%	−13%	−21%	52%	14%	22%	−30%	61%
13	F		0%	11%	−42%	70%	−96%	−100%	100%	40%	−8%	−24%	−6%	24%	8%	36%	−10%
14	F		0%	−22%	−38%	−32%	−62%	−3%	25%	−32%	−100%	100%	15%	80%	207%	−5%	1%
15	F		0%	−38%	−24%	16%	−4%	−39%	32%	5%	−31%	34%	19%	52%	−26%	35%	20%

[a] No HRV recording.

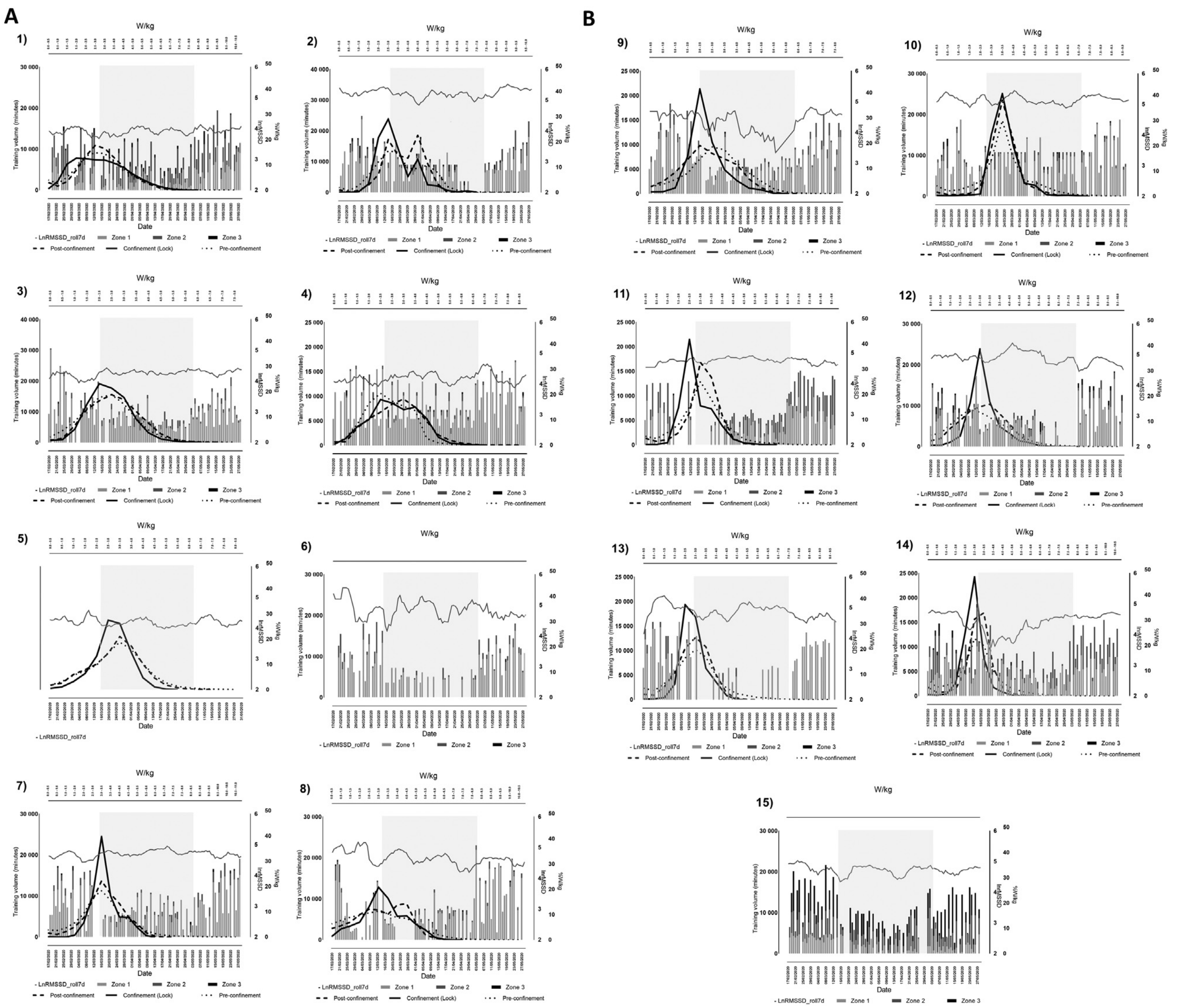

Figure 2 Male (A) and female (B) individual training volume, intensity and HRV. Grey coloured box represents the lockdown period. Bottom x-axis shows the dates of the measurement. Left y-axis shows the training volume expressed in minutes (grouped columns in bar chart), in which light grey represents zone 1, medium grey represents zone 2 and black represents zone 3. First right y-axis (grey line) shows the natural logarithm of the root mean squared differences of successive RR intervals averaged weekly (LnRMSSD_roll7d). Top x-axis show the power output recordings distributed into ranges of 0.5 W/kg^{-1}, represented in the second right y-axis as a percentage of time expended in the three different periods: pre-lockdown (dotted black), lockdown (black) and post-lockdown (dash black).

consistent with other researchers that found no group changes in LnRMSSD in elite athletes after increases and decreases in training load [28] ($n = 12$). This is also further supported by previous research that did not found relationship between HRV and training load but a positive relationship with changes in fitness and performance [29,30]. Unfortunately, due to the emergency situation lived and the nature of this study, pre- and post-measures of fitness could not be recorded.

The lack of performance measures is a limitation of our study, as well as the low sample size. However, note that if HRV was robustly associated with training volume and intensity one would have expected a clear pattern at the individual level and as a function of the period (pre-lockdown, lockdown, and post-lockdown). This was not the case, casting doubt on the previous studies with small sample size that reported positive findings at the group level. In any case, in the era of personalized training, we consider that

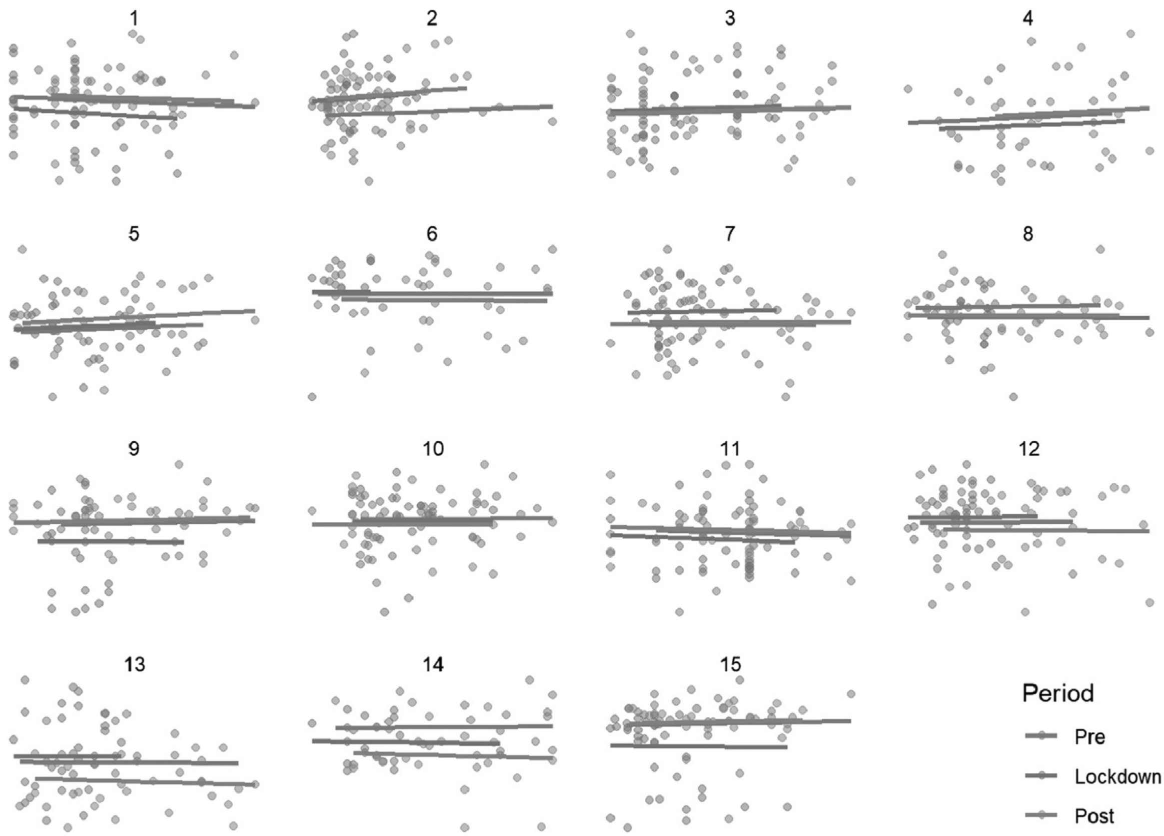

Figure 3 Model prediction per each subject and each period.

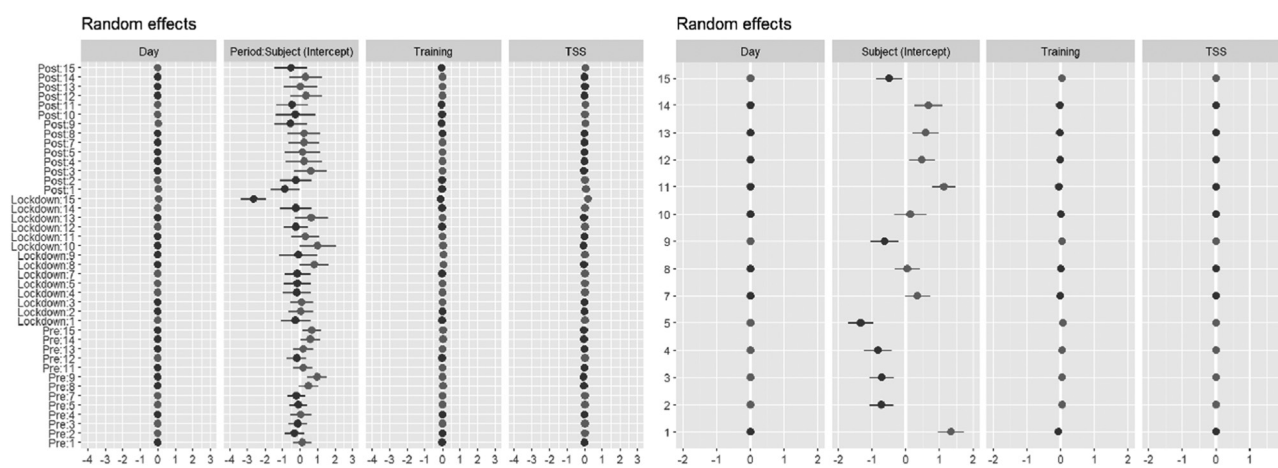

Figure 4 Random effects of the mixed model.

finding a statistically significant small group effect in a large sample might be meaningless in apply terms.

6. Practical applications

The mandatory lockdown (7 weeks) caused by the COVID-19 global pandemic produced an overall significant decrease in training volume in our group of professional road cyclists. However, the individualised programs carried out by these elite athletes elicited high inter-individual variability in the training intensity. HRV did not show a clear pattern of response linked to training load and/or intensity, suggesting that it might not be a sensitive and reliable tool to monitor training changes in elite cyclists.

Table 2 Results of the statistical analysis (mixed model) used in this study.

Observations	931
Dependent variable	HRV
Type	Mixed effects linear regression
AIC	1785.45
BIC	1916.03
Pseudo-R^2 (fixed effects)	0.00
Pseudo-R^2 (total)	0.68

Fixed effects

	Est.	S.E.	*t* val.	d.f.	*P*
(Intercept)	−0.04	0.25	−0.17	14.66	0.87
Training	−0.10	0.07	−1.40	123.33	0.17
Day	−0.00	0.00	−0.51	25.83	0.61
TSS	0.10	0.07	1.49	189.08	0.14
Training: Day	0.00	0.00	0.99	256.90	0.32
Day:TSS	−0.00	0.00	−0.62	257.15	0.54

Random effects

Group	Parameter	Std. Dev.
Period: subject	(Intercept)	0.71
Period: subject	TSS	0.05
Period: subject	Training	0.04
Period: subject	Day	0.01
Subject	(Intercept)	0.80
Subject	TSS	0.00
Subject	Training	0.04
Subject	Day	0.00
Residual		0.57

Grouping variables

Group	# Groups	ICC
Period: subject	41	0.35
Subject	14	0.43

Est: Estimate; S.E: standard error; T val: T value; d.f: degrees of freedom; *P*: *P*-value; AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion; ICC: Intraclass correlation coefficient. *P* values calculated using Satterthwaite d.f.

Disclosure of interest

The authors declare that they have no competing interest.

Availability of data and material

All data is available to readers through their request to the corresponding author.

Author contribution statement

A.J and M.M.M conceived of the presented idea. A.J, J.L. and M.M.R developed the theory and performed the data acquisition. D.M. performed the statistical analyses. D.S, D.M. and M.M.R verified the analytical methods and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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