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Brief Report

Heart Rate Variability in Elite Swimmers before, during and after COVID-19 Lockdown: A Brief Report on Time Domain Analysis

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Abstract: *Background:* Many athletes worldwide have endured home confinement during the COVID-19 pandemic, and their opportunities to train were strongly limited. This study describes the impact of lockdown on training volume and heart rate variability (HRV) in elite swimmers. *Methods:* HRV data of seven elite males were collected each Monday morning over 20 weeks, including 8 weeks of lockdown. The training volume was quantified retrospectively. *Results:* During the lockdown period (weeks 4–11) swimming was not allowed, and the total training volume was reduced by $55.2 \pm 7.5\%$ compared to the baseline volume (from 27.2 to 12.2 training hours). This drop was associated with a decrease in vagal activity (a $9.2 \pm 5.4\%$ increase in resting HR and a $6.5 \pm 3.4\%$ decrease in the natural logarithm of rMSSD from baseline values). After the lockdown (weeks 12–20), the training volume was gradually increased before attaining 68.8% and 88.2% of the baseline training volume at weeks 15 and 17, respectively. Resting HR and Ln rMSSD returned to baseline values four weeks after the lockdown. *Conclusions:* The lockdown period induced a decreased training volume which was associated with a decrease in vagal activity. However, HRV values returned to the baseline 4 weeks after the resumption of swimming training.

Keywords: physiology; swimming; monitoring; training load; home confinement

1. Introduction

As a result of the coronavirus disease (COVID-19) pandemic across the globe in 2020 [1], elite athletes along with the rest of the population were required to self-isolate and stay at home [2]. Due to the closure of public facilities, such as swimming pools and gyms, the possibilities to train were restricted to physical training at home with limited equipment [3], which often resulted in a decreased total training load and reduced training specificity, particularly evident in the case of swimmers. In addition, the postponement of most international events, such as the Olympic Games, deprived elite athletes of short-term performance objectives, after being psychologically and physically focused on the Tokyo Olympics for several months [3]. This new situation could be perceived as very stressful and may have led to the adoption of lifestyle habits that could be detrimental to physiological capacities [3].

Some studies have already highlighted that the lockdown had a negative impact on mental health in elite athletes [4–6]. Other authors have shown that lockdown has induced

some physical impairment in elite athletes, with a reduction in endurance capacity in elite handball players [7] and an increase in body mass in combat sports athletes [8]. This was in line with another study which described an increase in resting heart rate after 4 weeks of lockdown in elite swimmers [9], which was associated with a reduction in training volume and a decrease in the state of well-being.

The monitoring of heart rate, and especially heart rate variability (HRV), could be considered as one of the most informative and easy to obtain tools to track fitness status in elite athletes, as testing “on-the-field” was not possible during the lockdown. HRV is the analysis of the time intervals between heart beats, used to assess the functioning of the sympathetic and parasympathetic branches of the nervous system. Ultimately, this allows inferences to be made on the athlete’s adaptations to training in relation to training type, training volume, or training intensity [10]. The root mean square of the difference between adjacent normal RR intervals and a time interval (rMSSD) index seems to be the most relevant index to assess parasympathetic activity in elite athletes [10], whereas the standard deviation of normal-to-normal RR intervals (SDNN) is the gold standard for medical stratification of cardiac risk [11]. In the short term, both indices could give an indication of athlete fatigue and their wellness state. The association between heart rate and HRV indices could help coaches and support staff to interpret long-term training adaptations [10].

The HRV assessment seemed to be useful during the lockdown, where important changes in training characteristics occurred for elite athletes, which was particularly the case for swimmers who were unable to complete any sport-specific training. Previous studies investigated changes in the autonomic cardiac balance in line with training changes in swimmers. Atlaoui et al. showed a positive correlation between parasympathetic indices and performance in elite swimmers [12]. Conversely, two studies found a shift towards sympathetic dominance during the taper period, associated with a high pre-competition anxiety level and reduced parasympathetic activity [13,14]. Pla et al. also demonstrated that training volume and training intensity have a considerable impact on HRV responses, depending on the mesocycle plan [15].

Therefore, the objective of this brief report is to describe the effects of the COVID-19 crisis in elite swimmers, with a focus on (1) training characteristics and (2) HRV changes before, during, and after an 8-week lockdown period. It could allow coaches and support staff to quantify the impact of such situations on the cardiovascular and global health of their athletes.

2. Materials and Methods

2.1. Subjects

Seven elite male swimmers from the National Training Center (INSEP, Paris, France) participated in the study. The participants’ age, height, body mass, and FINA points were 21 ± 2 years, 189 ± 7 cm, 84 ± 8 kg, and 842 ± 58 points (100 m and/or 200 m specialists), respectively. All participants had been part of the French national swimming team in the last two years, at either junior or senior level.

2.2. Data Collection

Athletes performed a standardized HRV test, as previously described by Pla et al. [15]. Briefly, the test consisted of 6 min in the supine position in a calm environment, without moving or talking, with their arms positioned along their body. Each test was conducted on Monday morning, just after awakening, and after at least one and half days of rest (no exercise activity). RR intervals (the time elapsed between two successive R-waves of the QRS signal on the electrocardiogram) were recorded with an HR belt (Polar H10, Polar Electro Oy, Kempele, Finland) and transmitted by Bluetooth using a smartphone application (Elite HRV, USA). RR interval recordings were analyzed from the last 240 s of the test. Breathing rate was not guided. During the first step, no Kubios filter was used. The Kubios filter algorithm compared every RR (Gloucester, MA, USA) interval value against

a local average interval. Then, a medium filter was used, considering that the strongest filters could over-filter the signal. In the second stage, each data file was visually inspected in shortened windows for artifacts, which were manually corrected. Three time domain indices were used for the HRV analysis: heart rate (HR), Ln rMSSD (natural logarithm of the square root of the mean sum of the squared differences between RR intervals), and SDNN (standard deviation of normal-to-normal RR intervals).

Training volume was quantified with the athletes' coach before and after the lockdown period (strength training and swimming). All training sessions were monitored by the same coach. The study period comprised seven mesocycles, as follows. Before the lockdown (BEF), swimmers were involved in a training camp, which ended four weeks before the national championships (which were cancelled after the surge of the COVID-19 pandemic). This training camp was characterized by a high training volume and relatively high-intensity work. This period ended with the beginning of lockdown. A self-reported training volume (in hours) questionnaire was conducted on each Monday during the lockdown period (LOCK), including strength training and aerobic training volume (typically including a stationary bike, outdoor cycling or running, indoor rowing, etc.). The swimmers were not able to swim at all, had limited equipment to perform aerobic training, and were required to limit training intensity. The swimmers were requested to complete an online questionnaire to facilitate the data collection. This technique is commonly used by this group of swimmers during the training season. The first week after the lockdown (AFT1) was characterized by a higher aerobic volume, but with absolutely no intensity and still with no swimming sessions. The next two weeks (AFT2–3) were characterized with the resumption of one daily swimming session with no intensity and mainly aerobic and technique training, but no more aerobic land-based training. The next two weeks were (AFT4–5) characterized by an increase in training volume, with a majority of training performed under the first lactate threshold. It was also characterized by the re-turn of twice-daily sessions, three times per week. Then, the last four weeks of the study (AFT6–9) were characterized by a return of the classical 11 weekly swimming sessions. However, the intensity was still limited, and it was very rare for the coach to ask for an intensity above the second lactate threshold. It is also important to note that no competition was organized during that period.

2.3. Statistics

Data were analyzed using magnitude-based inferences in order to assess practical significance [16]. We used this approach in order to quantify the magnitude of changes between periods which appeared more relevant to monitoring the training load. RMSSD and SDNN were log transformed before analysis to reduce bias arising from the non-uniformity of error. To compare within-period changes between periods, we used a modified statistical spreadsheet [17]. The magnitude of the percentage group changes in all variables (training load, HR, Ln RMSSD, and Ln SDNN) was interpreted by using the smallest worthwhile change (SWC), which was defined as a small standardized effect based on Cohen's effect size (ES) principle ($0.2 \times$ between-athlete standard deviation) [16]. To analyze the group changes between weeks, we calculated the smallest worthwhile change (SWC) in HR, Ln RMSSD, and Ln SDNN, using the between-swimmers standard deviation (SD) of the averaged baseline variable (e.g., 0.2 multiplied by the between-swimmers SD of the mean variable baseline values). To calculate this SWC, we collected the weekly mean variable from September to March 2020 (training volume, HR, Ln rMSSD, and Ln SDNN), giving an overall baseline value. Then, we calculated the standard deviation between each swimmer's baseline value. The data were analyzed using effect size Cohen's *d* and interpreted as follows: <0.2 , trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; >1.2 , large [16]. We calculated probabilities to interpret whether the true differences were lower, similar, or higher than the SWC [16]. Quantitative chances of variable changes were also evaluated qualitatively, as follows: 25% to 75%, possibly; 75% to 95%, likely; 95% to 99%, very likely;

>99%, almost certain. If the chance of higher or lower differences was >5%, then the true difference was assessed as unclear [16].

3. Results

3.1. Training Volume

The weekly training volume is presented in Figure 1A. The baseline training volume was 27.2 ± 0.9 h (mean \pm standard deviation) but dropped to 12.2 ± 2.2 h during the lockdown ($-55.2 \pm 7.5\%$). This training volume was maintained during the three weeks after the lockdown (12.9 ± 0.8 h). During weeks 4 and 5 after the lockdown, the training volume increased to 18.9 ± 0.9 h ($69.5 \pm 2.1\%$ of baseline training). Finally, from weeks 6 to 9 after the lockdown, the training volume was increased to 24.6 ± 1.6 h ($90 \pm 3.3\%$ of baseline training). Details of the training schedule are presented in Table 1.

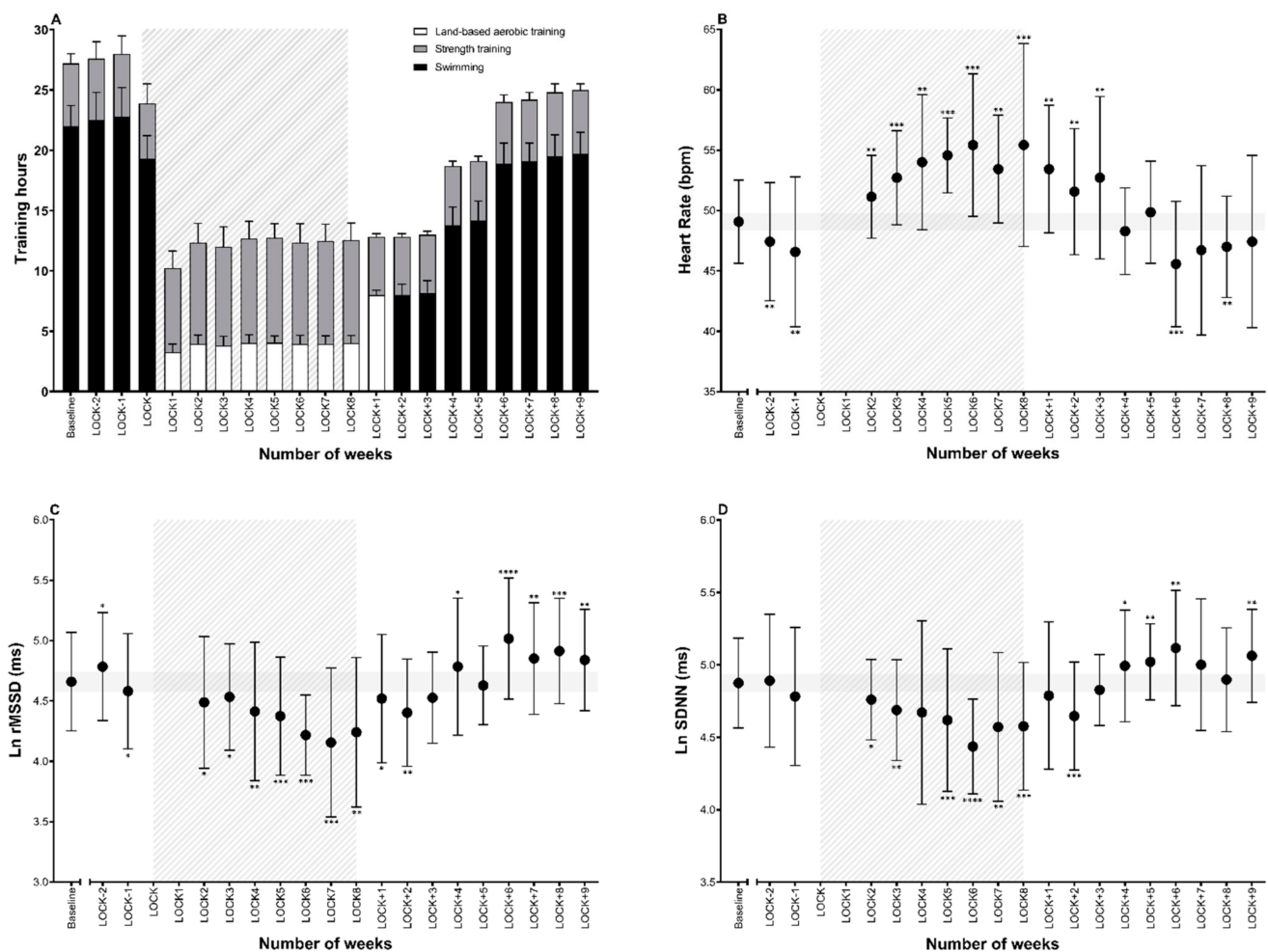


Figure 1. (A) Weekly training volume (in hours), (B) heart rate, (C) Ln RMSSD, and (D) Ln SDNN changes with SD for 7 elite swimmers before, during, and after lockdown (lockdown period is represented by dashed area). The grey shaded area indicates the smallest worthwhile change ($0.2 \times$ between-athlete standard deviation at baseline) for heart rate, Ln RMSSD, and Ln SDNN. * = “possible”, ** = “likely”, *** = “very likely”, and **** = “most likely” changes in HR, Ln RMSSD, and Ln SDNN indices.

Table 1. Overview of the training program performed during each period of the study.

Training Period	Date	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Baseline	AM	Swimming	Swimming	Swimming	Swimming	Swimming	Swimming	Rest
	PM	Swimming + ST	Swimming + ST	Swimming + ST	Swimming + ST	Swimming + ST	Rest	Rest
BEF	AM	Swimming	Swimming	Swimming	Swimming	Swimming	Swimming	Rest
	PM	Swimming + ST	Swimming + ST	Swimming + ST	Swimming + ST	Swimming + ST	Rest	Rest
LOCK	AM	Aerobic	Flexibility	Aerobic	Flexibility	Aerobic	ST or Aerobic	Rest
	PM	ST	ST	Flexibility	ST	ST	Rest	Rest
AFT1	AM	Aerobic	Aerobic	Aerobic	Aerobic	Aerobic	Rest	Rest
	PM	ST	ST	ST	ST	ST	Rest	Rest
AFT2–3	AM	Swimming	Swimming	Swimming	Swimming	Swimming	Rest	Rest
	PM	ST	ST	ST	ST	ST	Rest	Rest
AFT4–5	AM	Swimming	Swimming	Swimming	Swimming	Swimming	Rest	Rest
	PM	Swimming + ST	ST	Swimming + ST	ST	Swimming + ST	Rest	Rest
AFT6–9	AM	Swimming	Swimming	Swimming	Swimming	Swimming	Swimming	Rest
	PM	Swimming + ST	Swimming + ST	Swimming + ST	Swimming + ST	Swimming + ST	Rest	Rest

Note: BEF = before lockdown; LOCK = during lockdown; AFT1 = one week after lockdown; AFT2–3 = two to three weeks after end of lockdown; AFT4–5 = four to five weeks after end of lockdown; AFT6–9 = six to nine weeks after end of lockdown; ST = strength training.

3.2. HRV Changes

HR, Ln RMSSD, and Ln SDNN changes are presented in Figure 1B–D. The baseline was 49.1 ± 3.5 bpm, 4.7 ± 0.4 ms, and 4.9 ± 0.3 ms for HR, Ln RMSSD, and Ln SDNN, respectively.

During the two weeks preceding the lockdown, a small decrease ($-4.6 \pm 4.8\%$) in resting HR was observed from baseline values, whereas changes in Ln rMSSD and Ln SDNN were unclear. During the lockdown, a small to large increase in resting HR was observed ($+9.2 \pm 5.4\%$). For Ln rMSSD and Ln SDNN, a small to moderate decrease was observed ($-6.5 \pm 3.4\%$ and $-5.3 \pm 3.1\%$ for Ln RMSSD and Ln SDNN, respectively). After the end of lockdown, differences between baseline values became unclear after 5 weeks for Ln rMSSD resting HR. For the final four weeks of the study, a small to moderate decrease in resting HR was observed ($-5.4 \pm 4.8\%$), along with a small to moderate increase in Ln rMSSD from baseline values ($5.3 \pm 2.1\%$). Unclear results were observed for Ln SDNN after the lockdown period. Detailed HRV values are provided in Table 2.

Table 2. Changes in mean as Cohen effect size (ES) and $\pm 90\%$ confidence limits (CL) with quantitative chances (inference) of substantial differences for heart rate (HR), Ln RMSSD, and Ln SDNN over the 20-week period. Percentage changes are compared from baseline (which was estimated using 16 ± 2 Monday tests).

Weeks	Heart Rate				Ln RMSSD				Ln SDNN			
	ES	CL	Inference	p-Value	ES	CL	Inference	p-Value	ES	CL	Inference	p-Value
0–1	−0.34	0.32	1/21/78	0.09	0.25	0.19	70/30/0	0.04	0.04	0.63	31/44/25	0.92
0–2	−0.43	0.52	3/18/79	0.16	−0.15	0.25	2/62/37	0.28	−0.20	0.57	11/39/50	0.52
0–3	X	X	X	X	X	X	X	X	X	X	X	X
0–4	X	X	X	X	X	X	X	X	X	X	X	X
0–5	0.52	0.67	81/15/4	0.18	−0.31	0.35	1/27/72	0.14	−0.34	0.39	2/24/74	0.15
0–6	0.86	0.48	98/2/0	0.01	−0.26	0.38	3/36/61	0.23	−0.49	0.54	2/14/83	0.13
0–7	0.92	0.81	93/5/2	0.07	−0.43	0.39	1/14/85	0.08	−0.35	0.63	7/26/68	0.31
0–8	1.46	0.91	98/1/1	0.02	−0.55	0.31	0/3/97	0.01	−0.54	0.34	0/5/95	0.02
0–9	1.14	0.63	99/1/0	0.01	−1.03	0.68	1/2/97	0.03	−1.20	0.44	0/0/100	0.00
0–10	0.95	0.82	94/5/2	0.07	−0.84	0.41	0/1/99	0.01	−0.62	0.53	1/7/91	0.06
0–11	0.86	0.64	96/4/1	0.04	−0.69	0.53	1/5/94	0.04	−0.68	0.39	0/2/97	0.01
0–12	0.85	0.65	95/4/1	0.04	−0.26	0.39	3/36/61	0.25	−0.18	0.55	11/41/47	0.55
0–13	0.49	0.60	81/16/3	0.17	−0.52	0.36	0/6/93	0.03	−0.58	0.27	0/2/98	0.01
0–14	0.59	0.58	88/10/2	0.09	−0.30	0.54	6/31/63	0.33	−0.15	0.71	19/37/45	0.70
0–15	−0.19	0.47	8/43/49	0.46	0.22	0.32	54/43/2	0.23	0.30	0.38	68/30/2	0.18
0–16	0.18	0.57	47/41/12	0.57	−0.08	0.32	7/69/24	0.66	0.44	0.46	82/16/2	0.11
0–17	−0.69	0.44	0/3/96	0.02	0.68	0.23	100/0/0	0.00	0.59	0.41	94/5/1	0.03
0–18	−0.37	0.60	6/24/70	0.28	0.38	0.28	87/12/0	0.04	0.28	0.70	59/30/1	0.46
0–19	−0.47	0.47	2/14/84	0.10	0.52	0.24	98/2/0	0.01	0.06	0.61	34/44/22	0.86
0–20	−0.25	0.49	6/36/58	0.35	0.38	0.42	78/20/2	0.13	0.52	0.51	86/12/2	0.10

Note: Week 0 represents baseline measures. Weeks 1–2 represent the two weeks before lockdown commenced. Week 3 represents the first Monday of lockdown. Weeks 4–11 represent the weeks during lockdown. Weeks 12–20 represent the weeks after lockdown. Inference shows likelihood of changes being beneficial, trivial, and harmful. X = no data available.

4. Discussion

After collecting training load and HRV data on seven elite swimmers before, during, and after 8 weeks of lockdown without any swimming activity, it was noted that swimmers encountered a 55.2% training volume reduction during the lockdown, which was associated with a decrease in vagal activity (+9.2% in RHR and -6.5% in Ln rMSSD) and HRV global activity (-5.3% in Ln SDNN).

The lockdown period induced a decrease in weekly training volume from 27.2 to 12.2 h. The present data show a large increase in resting HR during this period, that was mainly mediated by a decrease in vagal tone and vagal control of the heart [18]. A recent study described the HRV profile of a world class open-water swimmer and demonstrated that HRV vagal-related indices were increased after a 50% increase in mean training volume [15]. Previous studies in elite endurance athletes have shown that a reduction in training load can lead to a decrease in vagal activity indices [10,18,19]. Other studies highlighted the impact of training cessation on the cardiac autonomic function with a reduced parasympathetic activity in endurance athletes [20–22]. Considering the association between the decrease in parasympathetic activity and the decline in cardiorespiratory fitness [23], these changes in HRV may reflect an alteration of one or more of the components of endurance performance [10].

In contrast, the changes in resting HRV and Ln rMSSD observed in this study also indicate an increase in sympathetic activity. A similar response has also been reported following a taper period which preceded an optimal triathlon race performance, brought about by a reduction in training volume and possible pre-race anxiety [19]. While these HRV responses may indicate a decline in aerobic fitness, although this was not measured in the present study, it is important to note that similar HRV responses can also be indicative of an optimal taper and readiness to perform. These similar HRV patterns can occur due to different contextual factors, and that reinforces the importance of interpreting HRV changes with additional markers of training status [24]. It is possible that swimmers experienced higher levels of stress or anxiety during the lockdown period due to a lack of certainty around training and competition schedules with the postponement of the Olympic Games, which may have contributed to the increase in sympathetic activity. This hypothesis could also be argued by the decrease observed in SDNN values during the lockdown period. Indeed, it has already been shown that anxious people have lower SDNN values compared with controls [25].

However, following a gradual increase in training volume and a return to swimming training after the lockdown, a progressive increase in vagal modulation was observed, highlighted by a decrease in resting HR and an increase in Ln rMSSD. It seems that despite the reduced training volume, mostly at the expense of swim-specific training, these swimmers were able to avoid excessive declines in cardiovascular function during the lockdown period, as recently described by Garcia-Pallares et al. [26]. The maintenance of land-based aerobic training during the lockdown likely helped to prevent this decline and to restore baseline HR and HRV values. Another key insight from these results is the observation that vagal activity appears to be higher in the last weeks of the study in comparison with the baseline values. Indeed, despite a lower training volume than during the baseline, rMSSD values are higher and HR values are lower than at baseline. During this post-lockdown period, the aerobic volume was likely sufficient to increase parasympathetic activation, but the total intensity level was possibly limited, which would explain a lesser dominance of orthosympathetic activity.

This case report presented some shortcomings that were difficult to overcome given the inability to have physical contact with the swimmers and to maintain a standardized training plan during this time. Therefore, it was not possible to objectively measure performance or to collect daily HRV measurements. Another limitation was the inability to control the swimmers' lifestyle given that factors such as the quality and quantity of sleep, diet, hydration, body mass, and menstrual cycles, have an impact on HRV indices. Finally, the training load was only quantified as training volume, as swimmers were not

able to report training intensity. Without an accurate training load quantification, it is more hazardous to interpret HRV changes and the results should be taken with caution.

5. Conclusions

During eight weeks of lockdown due to the COVID-19 pandemic, HRV changes observed in elite swimmers suggest that a decrease in training volume and a complete lack of swim-specific training may trigger a drop in endurance capacity. These negative changes in parasympathetic nervous system activity have previously been associated with detrimental effects on performance in rowing and triathlon events [18,19]. However, parasympathetic activity returned to baseline levels (pre-lockdown) approximately 4–5 weeks after the resumption of swimming training.

These results highlight the importance of remote training monitoring during such periods. Regular data collection on a daily or weekly basis allows support staff to observe individual changes in physical and mental health [27]. These data can assist background staff in determining appropriate loading as facilities re-open, allowing the resumption of swimming training. We observed a gradual and controlled increase in training volume after the lockdown period, which induced a quick return to baseline HR and HRV values.

Author Contributions: R.P. conceived the idea and collected the data. R.P. encouraged A.A., I.M., K.M. and L.B. to investigate the findings of this work. R.P. took the lead of the manuscript and was helped by A.A. to supervise the project. A.A. helped with the collection of references. R.P., K.M. and I.M. discussed the research direction. K.M. also helped with the English writing. All authors accepted the final version of the manuscript.

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Institutional Review Board Statement: All investigations conformed to the code of ethics of the World Medical Association (Declaration of Helsinki). A declaration of the study was made and approved by the Commission Nationale de l'Informatique et des Libertés (CNIL) with the following registration number: 2218805.

Informed Consent Statement: Prior to participation, athletes were informed of the purpose of the study and the data collection involved. Written consent was obtained. For athletes below the age of 18 years, written consent was provided by their parent/guardian.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author, R.P.

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Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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