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Adolescent Swimmers' Autonomic Modulation: Analyzing the Effects of the COVID-19 Confinement Period

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Abstract This study aimed to investigate the effects of compulsory confinement due to COVID-19 on young swimmers through their autonomic responses. It involved six elite athletes, with an average age of 15.20 ± 0.48 years (five males and one female, aged 15.09 years), monitored over 35 days. This period included 5 days prior to confinement, 12 days during confinement, 4 days during the first week of regular training post-confinement, and 7 days each in the second and third weeks of training. This study utilized two methods to assess the impact of training load on heart rate variability (HRV): the arbitrary units of load to quantify the training load and the log-transformed root mean square of successive R-R intervals (LnRMSSD) to evaluate HRV. Heart rate values were used to prescribe training tasks during confinement. The study observed significant changes in LnRMSSD over time, with a decrease during the confinement period ($F = 3.033$; $p = 0.019$) and a return to baseline levels for all swimmers by the third week of regular training. However, two swimmers who, on their initiative, performed an additional exercise program during confinement in addition to what the coach requested exhibited the opposite behavior by increasing the LnRMSSD value. The study suggests that the absence of regular swim training during confinement decreased HRV in most swimmers, which could be reversed or minimized by using non-specific training strategies. Also, the study highlights the practicality of HRV as a monitoring tool.

Keywords Heart Rate Variability, Swimming, Youth, Parasympathetic Nervous System, COVID-19 Pandemics

1. Introduction

COVID-19 has had a profound impact on athletes as well as the rest of the population who were forced to stay at home due to the pandemic [1]. Professional athletes had to adjust to the new rules and regulations put in place by the government, and many had to take a break from their sport due to the lack of facilities available to them. These measurements caused a decrease in total training load as well as a decrease in training specificity, particularly for swimmers. Consequently, training-induced morphological and physiological adaptations may be lost partially or completely as a result of insufficient and/or inappropriate training stimuli [2]. The decline in cardiorespiratory and neuromuscular adaptations (e.g. decreases of 4–14% in maximum oxygen uptake) is well documented after short-term (< 4 weeks) training cessation [3]. Previous studies reported that lockdowns had a negative impact on the mental health, and endurance capacity of elite athletes [4, 5]. In some cases, lockdown has been shown to cause physical impairment in elite athletes, including a reduction in endurance capacity in handball players [4] and an increase in body mass in combat sports athletes [6]. The lockdown circumstances also affected elite athletes' parasympathetic activity, resulting in a significant increase in heart rate (HR), especially in a standing position. The increased HR was associated with a decrease in training volume and well-being [7]. Heart rate variability (HRV) is an established monitoring tool known for its efficacy in tracking performance and fatigue levels, especially in elite sports settings [8, 9]. Keeping track of heart rate variability could be regarded a useful and accessible method for monitoring the physical condition or performance readiness of elite athletes. Additionally, it enhances our understanding of how the lockdown affects performance by observing changes in the status of the regulatory nervous system and cardiovascular system [10]. HRV is the analysis of time intervals between heartbeats, which vary due to adjustments made by the autonomic nervous system. It's used to assess the functioning of the sympathetic and parasympathetic branches, allowing clinicians to identify stress, fatigue, and other physical and mental states [11]. Additionally, HRV allows inferences to be drawn regarding the athlete's adaptation to training in relation to the type, volume, or intensity of training [8]. Short-duration HRV data collection has been proposed as a more convenient and still quite reliable alternative to the traditional method, which involves recording for approximately ten minutes [12]. The log-transformed root mean square of successive R-R intervals (LnRMSSD) is a vagal-related heart rate variability index. LnRMSSD is used to measure how the RR interval changes over time, which indicates the level of activity of the parasympathetic system in the heart [13]. It has been suggested that this measurement can be used as an appropriate marker for monitoring training, particularly during periods of rest, and can indicate how well an athlete adapts to the stress of training and competition [14]. It is recommended that LnRMSSD is monitored on a daily basis and that the weekly mean value is calculated [15].

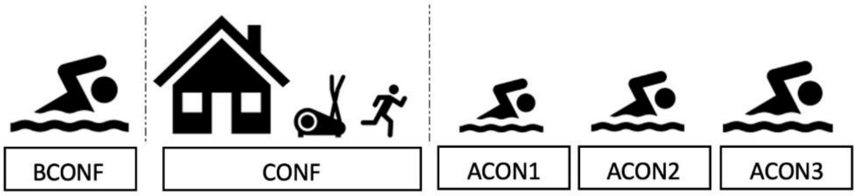
To our knowledge, no study has evaluated the effect of confinement on the temporal marker of RR interval change (The root mean square of successive differences between normal heartbeats (RMSSD) or LnRMSSD) in morning awakening period in elite young athletes. The purpose of this study was therefore to determine if compulsory confinement induced by Covid-19 affects the response of the natural LnRMSSD as a marker of adaptation to stress-inducing mechanisms in healthy young swimmers.

2. Materials and Methods

2.1. Participants

This study involved six Portuguese elite swimmers from the same swimming team, five males (ages: 15.20 ± 0.48 years) and one female (ages: 15.09 years). In terms of technical level, the sample clusters into a quite homogeneous group, recording 496 ±32.16 FINA points in the most recent official test, and with a training experience of six years. Given the rarity of elite teenage swimmers in our population, we conducted a power analysis based on the existing sample size. Using G*Power, we determined the necessary sample size for a one-tailed t-test with an effect size of 0.3 and a sample size ratio (b/a) of 0.36, achieving a statistical power of 0.80. Athletes were briefed on the study's objectives and the procedure for data collection prior to their involvement. Written consent was obtained from their parents or guardians. Protocols and experimental design followed the principles of the Declaration of Helsinki and were approved by the Ethics Committee of the Faculty of Sport Sciences and Physical Education (FCDEF), University of Coimbra (Reference: CE/FCDEF-UC/00662021).

The study used a prospective observational approach to collect HRV values each day in the morning and upon awakening. The data collection period lasted for 35 days, which corresponds to the micro-cycle (week) immediately before a 12-day period of mandatory home confinement ordered by health authorities which was followed by 3 weeks of resumption of regular training in the pool (Figure 1). Morning training sessions (AM) took place on Mondays and Thursdays, starting at 6:30 am and lasting 1:30 hours, and Saturdays, starting at 8 am and lasting 2 hours. Afternoon training sessions (PM), from Monday through Friday, starting at 7 p.m. and lasting until 2:00 a.m. Following waking up, each athlete collected HRV (RR interval). Athletes were instructed to maintain their collection schedule during confinement, which varied between 6 hours ±1:30 hours.



Note: BCONF: before confinement; CONF: during confinement; ACONF1: 1st week after confinement 1; ACONF2: 2nd week after confinement; ACONF3: 3rd week after confinement.

Figure 1. Conceptualization of the study

2.2. Measure

Athletes were instructed to perform HRV measurement for 5 min in the morning upon waking up, in the supine position and adjusting the chest strap transmitter around their torso at the level of the xiphoid process while remaining comfortably still, in their bed. To obtain the beat-to-beat HR signal, a chest strap with a Polar H7 Bluetooth transmitter (Polar, Electro, Oy, Kemple, Finland ®) with a collection frequency of 1000 Hz was used. HR was recorded using the validated EliteHrv® smartphone application [16]. When a stable heart rate is detected by the application, the user starts recording HRV signals. The RR interval is processed by the software and the values of RHR and the natural LnRMSSD are automatically calculated. The RMSSD component of HRV was used in the present study because of its reliability, validity, and practicability [17, 18]. After completion of an HRV measurement, the athletes were instructed to export and email the results to the investigator for analysis. Athletes were familiarized with the HRV recording procedure at a team meeting. They performed a 5-day test period prior to the start of the study to obtain HRV measurements upon awakening. All HRV recordings were obtained under spontaneous breathing conditions. Data were collected during 5 minutes of recordings. After collection, the first and last 2 minutes were discarded. Data were analyzed using Kubios HRV 3.0.0® software (Kubios Ou, Kuopio, Finland), and HRV parameters were evaluated in the time domain: RR interval; LnRMSSD [19].

2.3. Procedure

The daily training load was controlled by volume (km swum or time spent in training sessions) and intensity through the weighted value of the volume by the intensity zone [20]. The magnitude of the training load was calculated based on meters swum during the training session, weighted by the respective intensity zone [20]. The use of indices of difficulty was established based on the reference to the probable values of lactate accumulation normally associated with the different tasks performed in swimming training, i.e., the magnitude of load will then be expressed in arbitrary units of load (AUL). Table 1 presents the values obtained before and after confinement.

Athletes were asked to perform the scheduled work from Monday through Saturday during the 12-day confinement, keeping the same routines and habits they had before the confinement. Three online training sessions, each lasting 90 minutes and conducted via the Zoom platform and controlled by the trainer, followed the previous water training schedule. Additionally, there were three more sessions of continuous running at a specific level of intensity (HR 150 -160 bpm). The online circuit training consisted of four sets of 16 exercises, designed for general fitness aims, detailed in Table 2. Every set consisted of 30 seconds of work and 15 seconds of rest. At the end of each exercise, there was a 2-minute break. The following workout was added by two athletes on their own initiative after the coach's approval: Athlete BL performed six additional running workouts per week lasting 1:30 ± 0:30 hours with an HR of 150 ± 15 bpm; athlete VC performed 6 more cycle ergometer workouts per week lasting 1:30 ± 00:30 hours and with a HR of 140 ± 20 bpm.

2.4. Analysis

The results are presented as mean and standard deviation. A comparative analysis was conducted to analyze the mean LnRMSSD values at each microcycle for all participants as a group and individually using mixed effects analysis via Friedman nonparametric repeated measures and Dunn's post hoc test. The significance level was set at $p<0.05$. All analyses were conducted with Prism 9 version 9.4.1.

3. Results

The average weekly swim training volume is presented in Table 1. The baseline training volume was 5644±1918 m but dropped to zero during the lockdown. During the first week after the confinement, the training volume increased to 3667±764 m. Finally, in the second week after the confinement, the training volume increased to 5300±2604 m, and the week after returned to the baseline value of 5663±2102 m.

The mean weekly values of LnRMSSD are reported in Table 3. Considering the whole sample, a significant variation was observed over the study period, with this indicator decreasing during the confinement, although in a more pronounced way in the first week of return to regular training (F = 3.033; p = 0.019).

Table 1. Training load in the 4 micro cycles before and after confinement

	A1	**A2**	**A3**	**A4**	**TL**	**AA**	**TÉC**	**TV(m)**	**ATV ±SD (m)**	**AUL**	**AI(AUL) ±SD**
BC	19900	10800	200	300		450	13500	45150	5644±1918	10,71	1,34±0,48
C											
AC1	7900	1000				100	2000	11000	3667±764	3,49	1,16±0,15
AC2	19400	7600	4000		800	1100	14800	47700	5300±2604	14,56	1,62±0,72
AC3	30110	3200	4100	1200		390	6300	45300	5663±2102	11,08	1,39±0,69

Note: BC: before confinement; C: Confinement; AC1:1 week after confinement; AC2:2 weeks after confinement; AC3: 3 weeks after confinement; A1: light aerobic, HR = 120 bpm; A2: medium aerobic HR = 120 - 140 bpm; A3: anaerobic threshold HR = 150 - 165 bpm; A4, maximal aerobic power; TL: lactate tolerance; AA: Anaerobic a lactic; TEC: technical training; TV: total volume; ATV: average total volume; SD: standard deviation; ALU, arbitrary load units; AI: average intensity.

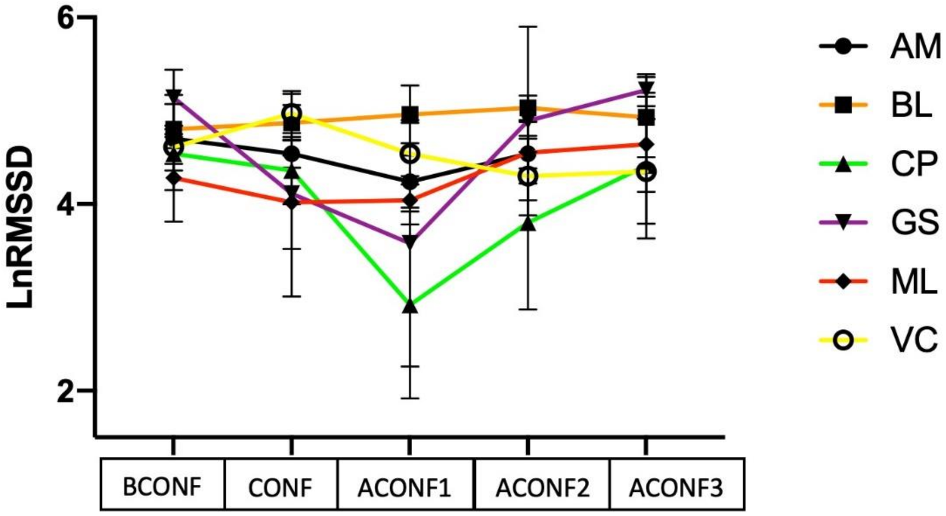
Table 2. Structure of exercise session during confinement

Day	Activity	Volume/intensity	Rest within the set: rest between exercise	Session duration
Monday	Online circuit training Jumping jacks, High Knees, Push-ups, Arm circles, Knee-to-elbow, jumping lunges, Basic burpees, Plank hold, Elbow plank hold, Bounce + squat, Shoulder taps, Climbers, Punches, Wide plank hold, Bicep extensions, Side leg raises	4*30s	15s:2min	90 minutes
Tuesday	Continuous running	HR 150-160 bpm	-	45 minutes
Wednesday	Online circuit training	4*30s	15s:2min	90 minutes
Thursday	Continuous running	HR 150-160 bpm	-	45 minutes
Friday	Online circuit training	4*30s	15s:2min	90 minutes
Saturday	Continuous running	HR 150-160 bpm	-	45 minutes
Sunday	-	-	-	-

Table 3. Descriptive values of the weekly mean Ln RMSSD upon awakening

Week / Subject	BC	C	AC1	AC2	AC3	P-Value
AM	4,70 ±0,10	4,54 ±0,15	4,24 ±0,28	4,54 ±0,16		0,001**
CP	4,54 ±0,18	4,36 ±0,36	2,92 ±1,00	3,80 ±0,93	4,41 ±0,78	0,077
GS	5,14 ±0,30	4,11 ±1,10	3,58 ±1,32	4,89 ±1,01	5,22 ±0,17	0,014*
ML	4,28 ±0,47	4,02 ±0,50	4,04 ±0,26	4,55 ±0,33	4,64 ±0,51	0,028*
BL	4,80 ±0,37	4,87 ±0,19	4,96 ±0,31	5,03 ±0,13	4,93 ±0,43	0,410
VC	4,61 ±0,46	4,97 ±0,21	4,54 ±0,33	4,30 ±0,26	4,35 ±0,56	0,001**
Averge	4,68 ±0,42	4,49 ±0,63	4,07 ±0,92	4,52 ±0,70	4,72 ±0,59	0,019*

Note: * <0.005; ** <0.001; BC: before confinement; C: Confinement; AC1:1 week after confinement; AC2:2 weeks after confinement; AC3: 3 weeks after confinement



Note: BCONF, before Confinement; CONF, Confinement; ACONF1:1 week after confinement; ACONF2: 2 weeks after confinement; ACONF3: 3 weeks after confinement.

Figure 2. The LnRMSSD value before, during and after the confinement period

However, two different patterns were detected in the morning LnRMSSD. Looking at the athletes' profiles, four subjects followed the same pattern mentioned above.

However, subjects BL and VC showed opposite behavior, increasing the LnRMSSD value in the confinement period (Figure 2). These athletes performed an additional physical exercise program.

4. Discussion

The study found that a decrease in training volume during a lockdown led to a reduction in parasympathetic activity as measured by LnRMSSD. However, once the lockdown was lifted, the training volume increased, leading to a corresponding increase in LnRMSSD. The study also identified two athletes who followed an additional exercise routine during the lockdown period and experienced an increase in LnRMSSD in contrast to other athletes who did not. The study observed a substantial 75.63% reduction in training volume during the first week after confinement. This reduction was associated with a notable decrease in vagal activity, as evidenced by a 13% decline in LnRMSSD. Research has indicated that during intense training regimens, there is a notable rise in parasympathetic activity. Conversely, during tapering periods, it's suggested that orthosympathetic activity might become more prominent, largely due to a decline in parasympathetic activity [9]. Reduced training volume may result in lower plasma volume and, consequently, lower HRV [21]. Our study findings align with previous research indicating that a decrease in workload can result in a reduction of Parasympathetic nervous system function among other elite athletes [17, 22]. According to Pereira's study, discontinuation of training affects cardiac autonomic function and reduces parasympathetic tone in endurance athletes [23]. Our results show that swimmers who had an additional training program (a larger training volume) had LnRMSSD values that remained high and consistent throughout the study period, which are similar to those reported by [24]. With higher LnRMSSD observed in these swimmers, it is highly likely that they could maintain aerobic capacity during the lockdown, mainly due to an increase in training volume and physical activity. During the lockdown period, despite the inability to engage in swimming training, swimmers were able to maintain their cardiovascular capabilities, which is in line with previous studies [24, 25]. Given that our athletes engaged in dry land training during this period, it's plausible that these sessions helped prevent significant declines in cardiovascular function and restore baseline HRV values. Particularly, continuous running sessions may have contributed, as athletes with higher aerobic fitness levels tend to experience faster reactivation of cardiac parasympathetic activity. Another explanation is that the lockdown period could have provided an additional opportunity for recovery to those swimmers who were more fatigued due to the training process. The study found that the coefficient of variation (CV) values were generally lower than those reported in previous studies [17, 18], ranging from 12.3% to 16.5%, which is relevant to the discuss of HRV indices in athletes. The lower CV values found in the study are positive findings because they indicate that the measure is consistent and reliable, which is important when examining HRV in response to stress-inducing mechanisms. Moreover, as LnrMSSD is minimally affected by respiratory rate [26] and capable of assessing acute parasympathetic response [27], it might be the most practical HRV index for athletes. This is particularly crucial considering the time constraints athletes face for measurement. Therefore, using LnrMSSD in conjunction with the low CV values found in this study may provide a reliable and practical means of monitoring HRV in athletes, especially when "on the field" testing is not feasible.

Finally, it is important to note that physiological and psychological responses to outdoor versus indoor environments could differ. However, the data on this matter is inconclusive, warranting careful consideration by coaches when designing training programs. For instance, one study observed higher power output and heart rate during outdoor cycling compared to indoor cycling. Despite similar environmental conditions [28]. Another study explored the acute effects of outdoor mountain hiking versus indoor treadmill walking, showing a stronger reduction in salivary cortisol levels during outdoor activity. However, no significant effects were found for blood pressure and heart rate variability [29]. This insight is particularly relevant for athletes like swimmers who incorporate outdoor training alongside their pool sessions.

Limitations

This study encountered several limitations: Firstly, we could not precisely quantify the training load due to the inability to have physical contact with the swimmers The swimmers were unable to provide detailed information about the intensity of their training. This lack of specificity in quantifying training load complicates the accurate interpretation of HRV changes, thus necessitating a cautious interpretation of the study results. Also, A larger sample size is required to fortify the internal and external validity of a study.

Moreover, the study did not control for athletes' lifestyle factors such as sleep quality and quantity, diet, and hydration. It also did not assess other relevant variables such as respiratory cyclic endurance, muscular endurance, and muscular ability, which could have provided deeper insights into real performance effects. Furthermore, psychological variables, known to be influential during the pandemic, were not monitored, representing another limitation of the study. It is highly recommended that future research considers addressing these limitations for a more comprehensive understanding of the subject matter.

5. Conclusions

The present study, the first of its kind, investigated the impact of Covid-19 confinement on young swimmers' autonomic responses and reported on HRV in swimmers under 18 years old during the Covid pandemic, revealing the critical role of regular physical activity in maintaining optimal parasympathetic activity. These results have practical importance for athletes and trainers, emphasizing the need to adapt training methods during periods of reduced volume. Further studies should explore the most effective types and intensity of physical activity for preserving parasympathetic activity.

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Conflicts of Interests

The authors report there are no competing interests to declare.

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