

## Article

# Cardiac Autonomic Effects of Yearly Athletic Retreats on Elite Basket Players: Usefulness of a Unitary Autonomic Nervous System Indicator

Daniela Lucini <sup>1,2</sup>, Leonarda Galiuto <sup>3,4,\*</sup> , Mara Malacarne <sup>1,2</sup>, Maria Chiara Meucci <sup>4</sup>  and Massimo Pagani <sup>1</sup>

- <sup>1</sup> BIOMETRA Department, University of Milan, Via Festa del Perdono, 7, 20122 Milan, Italy; daniela.lucini@unimi.it (D.L.); mara.malacarne@unimi.it (M.M.); massimo.paganiz@gmail.com (M.P.)  
<sup>2</sup> Exercise Medicine Unit, Humanitas Clinical and Research Center, Via Alessandro Manzoni, 56, 20089 Rozzano, Italy  
<sup>3</sup> Department of Cardiovascular Medicine, Fondazione Policlinico Universitario A. Gemelli IRCCS, Largo Agostino Gemelli, 8, 00168 Rome, Italy  
<sup>4</sup> Department of Cardiovascular and Pulmonary Sciences, Catholic University of the Sacred Heart, Largo Francesco Vito, 1, 00168 Rome, Italy; mariachiarameucci@gmail.com  
\* Correspondence: Leonarda.Galiuto@unicatt.it; Tel.: +39-06-30154187



**Citation:** Lucini, D.; Galiuto, L.; Malacarne, M.; Meucci, M.C.; Pagani, M. Cardiac Autonomic Effects of Yearly Athletic Retreats on Elite Basket Players: Usefulness of a Unitary Autonomic Nervous System Indicator. *Sustainability* **2021**, *13*, 2330. <https://doi.org/10.3390/su13042330>

Academic Editors: Santos Villafaina, Juan Pedro Fuentes García and Daniel Collado-Mateo

Received: 6 January 2021

Accepted: 14 February 2021

Published: 21 February 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Abstract:** In most sports athletic performance is determined by a combination of hard and soft modifiable components, encompassing physical and psychological elements that can be assessed with modern techniques based respectively on simple friendly methods: analysis of HRV and questionnaires. Specifically a novel % rank Autonomic Nervous System Indicator (ANSI) seems particularly useful also in elite sports. In this investigation we assessed ANSI capacity to detect the expected changes in cardiac autonomic regulation induced in the Italian basketball team by the participation (18 subjects) to the yearly biweekly Alpine training summer camp. We observed that ANSI increased from  $58.8 \pm 32.5$  to  $81.7 \pm 27.5$  (at the end of training camp) and did not change further in the subsequent initial weeks of competition season (overall  $p < 0.001$ ). Congruent changes were observed in non-linear indices. Concomitantly indices of somatic symptoms were slightly reduced just at the end of the alpine training. We conclude that analysis of HRV and questionnaires might offer a simple, useful technique to monitor changes in cardiac autonomic regulation and psychological state in elite athletes providing a convenient additional element to evaluation of training routines also in the fields.

**Keywords:** team sports; autonomic cardiac regulation; spectral analysis; stress; training

## 1. Introduction

In elite sports, athletic performance is determined by a combination of factors [1], reflecting physical, psychological and organizational domains. Substantial investment goes into intense training intended to integrate physical preparation (e.g., aerobic conditioning to sustain power output [2], nutrition titrated to individual athletes [3]), psychological/emotional maturation (e.g., resilience to stress) [4] and technical/tactical skills (particularly in team sports) [5] optimizing preparedness to competitions [6]. In addition, each sport may call for unique details of training, according to characteristic differences. Personalized intensity training might, e.g., be particularly beneficial in team sports, such as basketball [7], because the different playing positions define a unique combination of dynamic and static efforts throughout the competition [8], that (as in soccer [9]) might lead to individual differences.

Performance monitoring, which is highly dependent upon availability of individual metrics of training, may be facilitated by the recent observation that subjective self-reported measures may be trusted as evidence for athlete's well-being, in response to training loads [10].

Within the multidimension determinants of athlete's performance the autonomic nervous system plays a special role [1] as a bridge between physical and psychological elements.

Accordingly, a potentially useful method to follow individual changes in training, particularly with elite athletes [11], may be offered by Heart Rate Variability (HRV) [12]. This technique [13] has gained popularity (as documented by more than 50,000 hits in the MedLine database) for a combination of advantages. They are both practical (the technique is simple, inexpensive, totally non-invasive and non-intrusive and can be replicated frequently) and empirical (as a means to assess cardiac autonomic regulation, it is also obtaining growing attention in the sports area: there are now more than 4600 specific hits).

HRV (or the inverse RR interval  $V$ ) and particularly its frequency domain indices [14] seem to track faithfully cardiac neural remodeling attending variations in training volumes [15], quality of preparedness to compete [16] and subjective well-being [1].

Aerobic training, being associated to increased vagal and reduced sympathetic tonic drive, leads to lower resting HR and greater beat-by-beat variability, which is assessable with time domain measures, such as RR variance [17]. Its reduction, conversely, might suggest overtraining [18]. In addition the sympathetic-vagal (excitatory-inhibitory) balance is approximated by the normalized power of, respectively, the Low Frequency (LF) and High Frequency (HF) spectral components of HRV, synthesized in the LF/HF ratio [19]. A similar LF-HF balance is observed in directly recorded efferent sympathetic nerve activity [20] or in the activity of central neural nuclei [21], suggesting a common integrated closed loop organization from central to peripheral neural visceral circuits [20]. This behavior seems to replicate the arousal/performance umbrella-like Yerkes-Dodson [22] relationship of the noradrenergic nucleus ceruleus [23], which also supports the model of amplitude and frequency neural codes of autonomic functional organization [20,24].

In athletes and in aerobic specialties, with submaximal work-out training volumes, far from competition, there is a clear predominance of vagal modulation (higher HFnu) [25], while in proximity of the competition, with maximal volumes of activity, there is a shift towards sympathetic predominance, reflected by an increase in LFnu.

Regarding the proposal to use HRV as a means to follow the various steps of training [11], the presence of multiple HRV derived indices and lack of exercise-focused standards represents a potentially serious barrier to a widespread use of this approach [12,26].

To address this issue, after pondering various data reduction approaches, we observed that the combination of six HRV indices obtained at rest and during an ergometric test, after % ranking and controlling for age and sex, could be integrated by a radar plot into a % rank unitary proxy of cardiac autonomic regulation, named Autonomic Nervous System Index for sports (ANSIs) [27].

More recently we tested the use a further downsized Autonomic Nervous System Index (ANSI) and found it useful to recapitulate major linear indices (RR, RR variance, rest-stand change in low frequency spectral component in normalized units, i.e., LFnu) [28]. ANSI is by design insensitive to age and gender and easy to interpret thanks to the presentation as % rank (range 0–100, higher indicates better) based on a relatively large benchmark population [29]. We have utilized this approach with elite athletes [9,30,31], noncompeting individuals [32], as well as in ambulatory patient populations [33].

It should be added that in the last decade interest on non-linear algorithms to investigate complexity of HRV [34] increased considerably, paving the way to novel applications, particularly in conditions far from physiological rest and with low HRV signal. Recently it has been suggested that the combination of numerical indices with physical measures (e.g., HR) should be considered complementary and, particularly in cardiovascular pathophysiology [35], capable of providing additional informative value.

Goal of the present, proof of concept, study on a group of elite basket players is to verify whether ANSI [28] can describe the autonomic changes expected to occur following the two weeks long yearly athletic retreat in an Alpine village. As a secondary goal we

assess the concomitant effects on selected short term nonlinear indices related to entropy and pattern classification [36].

## 2. Materials and Methods

### 2.1. Study Population and Protocol

This proof of concept, observational, retrospective study is part of an ongoing series of investigations, focusing on the use of autonomic indices in cardiovascular health and prevention, following a general protocol that had been approved by Independent Ethics Committee Humanitas Research Hospital (Rozzano, Italy) on 13 October 2015. Data refer to the Italian national Basket team ( $n = 18$ ; age  $25.6 \pm 4.8$  years) who participated to the athletic retreat organized in an Alpine Italian village (about 1000 m altitude) after the detaining summer vacation, following the year-long competition season.

The protocol of this study adhered to the principles of the Declaration of Helsinki and Title 45, US Code of Federal Regulations, Part 46, Protection of Human Subjects, Revised 13 November 2001, effective 13 December 2001. All subjects had provided informed consent at the time of the visit, they were informed and agreed that their anonymized data could be used for scientific projects.

The good health of all participants was ensured by the team physician (who provided information on normalcy of biochemical values such as glucose and lipids) and confirmed by medical history and physical examination. Subjects were studied at entry (T0), after two weeks of training in the retreat (T1) and after subsequent two weeks of returning to compete (T2).

### 2.2. Autonomic Evaluation

Our approach to the non-invasive evaluation of autonomic regulation based on linear indices of short term Heart Rate Variability has recently been summarized [37]. In brief, after an overnight fast and a light breakfast, avoiding caffeine and intense physical activity in the preceding 24 h, ECG and respiratory activity (piezoelectric belt, Marazza, Monza, Italy) are acquired on a PC. Beat-by-beat data series of 5 min rest followed by 5 min upright data are analyzed off-line with dedicated software (AMPS-Ilc, New York, NY, USA) [38]. As described previously [37], from the autoregressive spectral analysis of RR interval a series of linear indices indirectly reflecting cardiovascular autonomic modulation is derived with minimal operator involvement (Table 1). The table also reports selected non-linear indices, reflecting regularity and pattern classification [34].

Figure 1 reports an example of spectral analysis of RR variability, as obtained with a dedicated software tool [38]. As shown in panel a, in normal subjects, three major components, indicated in red, are usually observed. In addition to a noise component around 0 Hz, they correspond to LF and HF oscillations, with a center frequency respectively of 0.03–0.14 Hz and 0.15–0.40 Hz. Smaller noise components may also be present, usually below 5% of oscillatory power. The SF application also permits to verify the existence of an elevated square coherence at HF between respiration (whose spectrum is shown in panel b) and RR variability (panel c). In this optimal case it corresponds to almost 1. At any rate also smaller values, at least greater than 0.5, indicate a significant exchange between RR interval and respiration; values smaller than 0.5 indicate non-significant coherence. This example shows the well-known phenomenon of the tachycardia accompanying inspiration (in this case the phase difference is about  $-2$  rad corresponding to about  $-120^\circ$ ). (reproduced from [32]).

Recordings of subjects with arrhythmias or low frequency breathing are discarded in order to avoid a bias which would render data uninterpretable [39].

Systolic and diastolic arterial pressure were measured using an electronic sphygmomanometer. The software provides also non-linear indices of RR variability, such as RRRo (index of regularity) and three beat pattern classification (P\_0v, P\_1v, P\_2lv, P\_2uv) [34].

**Table 1.** Definition of the linear RR and non-linear variability indices (ANS proxies) employed in the study.

Variables	Unit	Definition
HR	[beat/min]	Heart Rate
RR Mean	[msec]	Average of RR interval from tachogram sections
RR VAR	[msec <sup>2</sup> ]	RR variance from tachogram sections
RR LFa	[msec <sup>2</sup> ]	Absolute power(a) of Low Frequency (LF) component of RR variability V
RR HFa	[msec <sup>2</sup> ]	Absolute power(a) of High Frequency (HF) component of RRV
RR LFnu	[nu]	Normalized power (nu) of Low Frequency (LF) component of RRV
RR HFnu	[nu]	Normalized power (nu) of High Frequency (HF) component of RRV
RR LF/HF	[.]	Ratio between absolute values of LF and HF
RR LFHz	[Hz]	Center frequency of the RRLF AR spectral component
LFHFHz	[Hz]	Center frequency of the RRHF AR spectral component
RR-RESP HFHz	[Hz]	Peak frequency of the RR-RESP coherence function
RR-RESP HFK <sup>2</sup>	[.]	Peak frequency of the RR-RESP AR coherence function
$\Delta$ RRLFnu	[nu]	Difference of LF power in nu between stand and rest
ANSI	[%]	Composite unitary Autonomic Nervous System Index
RRRo	[.]	Regularity index
P_0v	[%]	Three beat pattern classification: 0 variations
P_1v	[%]	Three beat pattern classification: 1 variation
P_2lv	[%]	Three beat pattern classification: 2 like variations
P_2uv	[%]	Three beat pattern classification: 2 unlike variations

### 2.3. ANSI, a Proxy of Cardiac Autonomic Regulation (CAR)

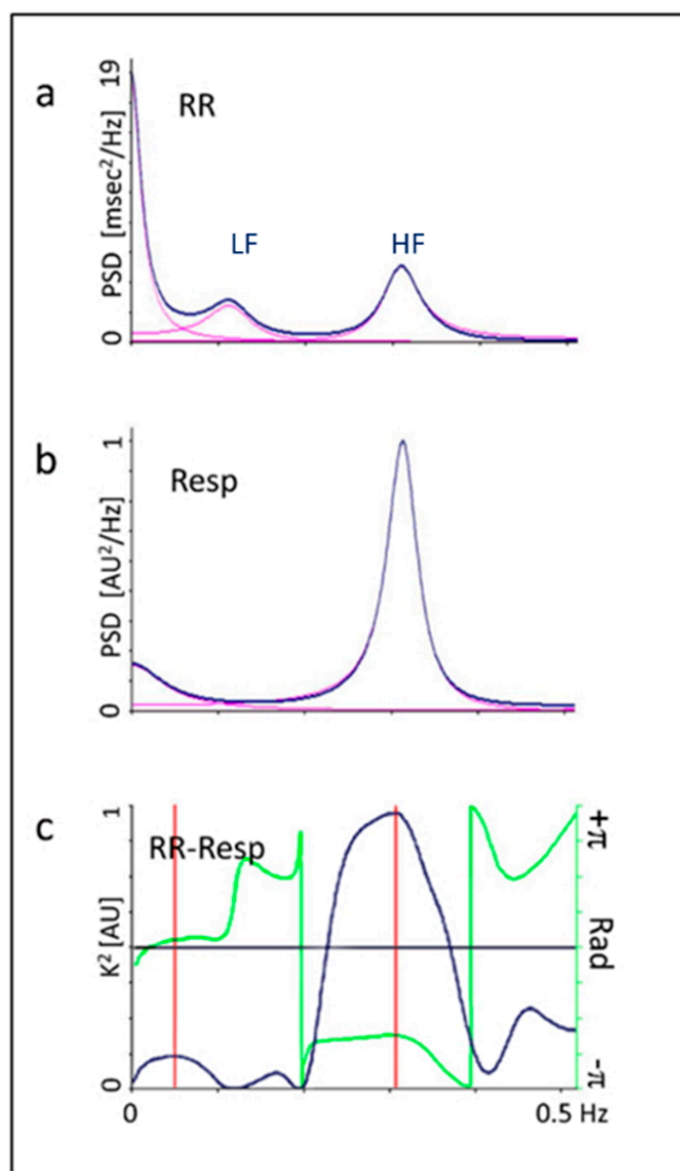
ANSI [28] was recently developed as a simple unitary proxy of CAR and the procedure employed for its computation is schematically summarized in Figure 2.

After spectral analysis of rest and stand short tachograms, data are subdivided according to gender and age. In addition, among all spectral derived proxies, three linear indices are selected as suggested by exploratory factor analysis, which indicates that the three most informative *latent factors* account for about 80% of data variance (VAF) [37].

These indices relate to domains of pulse, as well as amplitude and oscillatory aspects of RRV [36]. According to loading values, each *latent factor* may be represented by a single spectral index. In the present case the following indices result the most informative ones: RR Mean and RR VAR at rest, largely reflecting the vagal modulation and the stand-rest difference in RR LFnu, as an index of the effects of the sympathetic excitation mediated by baroreceptor unloading [20]. These variables are percent ranked and combined using a radar plot in a single proxy of CAR. The resulting ANSI, percent ranked against a benchmark population, easily indicates overall autonomic performance since simply low and high values reflect poor and good CAR, respectively.

### 2.4. Psychological Evaluation

The extent of stress and fatigue perception was assessed using a self-administered questionnaire [32] providing nominal self-rated Likert scales from 0 (“no perception”) to 10 (“highest perception”) for each measure. In addition somatic stress related symptoms scores were assessed by the 4SQ index that considers 18 items (each 0–10 range, total 0–180). These indices address respectively two major domains of stress: cognitive evaluation of stress or fatigue, and perception of bodily (somatic) symptoms.



**Figure 1.** Example of spectral analysis of RR variability. Panel (a) depicts an example of an autospectrum (PSD) of RR interval variability obtained at rest on a healthy subject. The overall spectrum is drawn in blue and individual components are shown in red (Low Frequency and High Frequency components, i.e., LF and HF, are indicated). Notice that ordinates should be multiplied by 1000. Panel (b) depicts an example of respiratory autospectrum. Notice that in this case only a single major component (at high, respiratory frequency) is observed, as typical of resting physiological breathing. Panel (c) depicts in blue the coherence function ( $k^2$ ) between RR interval variability (i.e., tachogram) and respiration signal. For completeness, the Phase function is also depicted (in green, from  $-\pi$  to  $+\pi$ ) (reproduced from [32]).

## 2.5. Statistics

The procedure to compute ANSI is summarized above (Section 2.3). Data are presented as mean  $\pm$  SD or model derived SEM. Differences between epochs were assessed with a Mixed Model Analysis followed by pairwise comparisons. A simple description of the method employed is available at [40,41]. Computations were performed using a recent statistical package (SPSS version 26, IBM, Armonk, NY, USA).

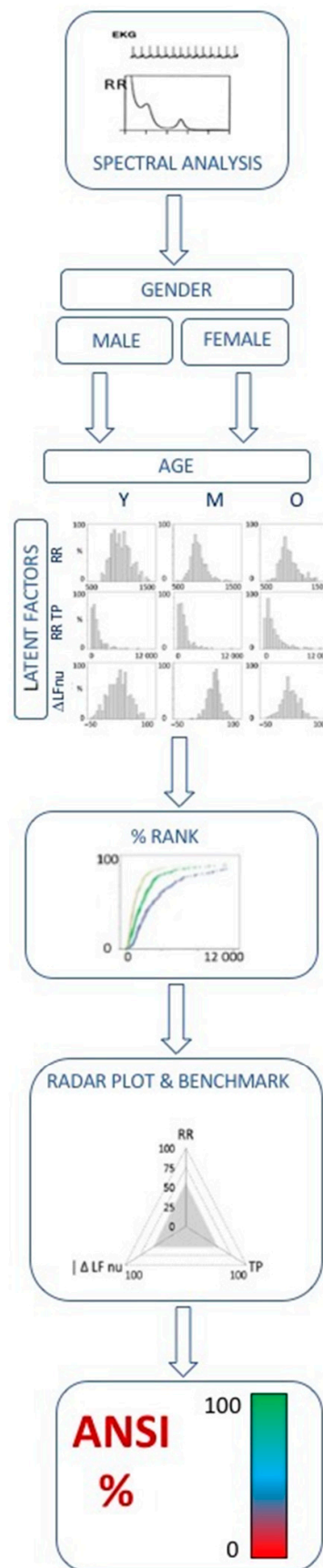


Figure 2. Schematic representation of the procedure employed to compute ANSI.



### 3. Results

Summary data from HR and RR interval beat by beat variability, employing spectral analysis and non-linear measures (Ro and pattern classification), together with subjective stress indices are presented in Table 2. It should be noted that these data refer to a small group of elite athletes and represent the ANS profile at the end of a few weeks period of free holiday, after the year-long competition season, without scheduled training: thus they are as much as possible, detraining values.

**Table 2.** Descriptive data (mean and standard deviation) of the ANS Proxies and stress indices in the three examined epochs: at baseline after free detraining (T1), after 2 weeks athletic retreat (T2) and after 2 weeks of resuming competitions (T3).

Variable	Unit	Epoch T1			Epoch T2		Epoch T3		<i>p</i>
		Mean	SD	Contrast	Mean	SD	Mean	SD	
HR	beat/min	58.40	9.22	* +	50.42	7.53	49.37	10.91	<0.001
RR Mean	msec	1051.83	171.74	* +	1212.91	167.35	1269.69	278.80	<0.001
RR TP	msec <sup>2</sup>	5330.21	6244.92	+	8737.72	7583.93	8325.24	5508.85	0.025
RR LFa	msec <sup>2</sup>	696.57	449.10	* +	1792.54	1694.55	2570.76	2098.96	<0.001
RR HFa	msec <sup>2</sup>	2705.42	4606.51		3285.92	4372.17	3144.80	2033.32	0.991
RR LFnu	nu	35.52	22.76		34.49	15.20	40.50	14.93	0.764
RR HFnu	nu	60.37	23.89		63.98	14.58	57.88	13.65	0.888
RR LF/HF	au	0.86	0.78		0.68	0.72	0.81	0.55	0.692
RR LFHz	au	0.09	0.02		0.10	0.02	0.10	0.02	0.658
RR HF	Hz	0.24	0.07		0.27	0.05	0.27	0.05	0.313
RR-RESP HF	Hz	0.24	0.07		0.27	0.07	0.27	0.06	0.161
RR-RESP HFK <sup>2</sup>	.	0.84	0.17		0.88	0.14	0.81	0.20	0.383
ANSI	%	53.83	32.56	* +	81.07	27.50	77.44	26.86	0.007
RR Ro	.	0.29	0.10	* +	0.17	0.08	0.20	0.08	0.03
P_0v	%	17.35	11.59	* +	11.50	7.78	12.52	8.27	0.028
P_1v	%	46.16	7.25		40.14	10.65	42.07	9.02	0.107
P_2lv	%	15.27	11.88		12.15	5.81	10.74	5.04	0.296
P_2uv	%	21.23	11.05	* +	36.21	17.17	34.67	14.23	<0.001
Stress	au	1.75	1.82		1.40	1.64	0.91	0.83	0.141
tired	au	2.33	1.30		2.20	2.08	1.82	1.33	0.583
4SQ	au	14.42	13.65	*	10.27	13.08	14.55	12.83	0.009

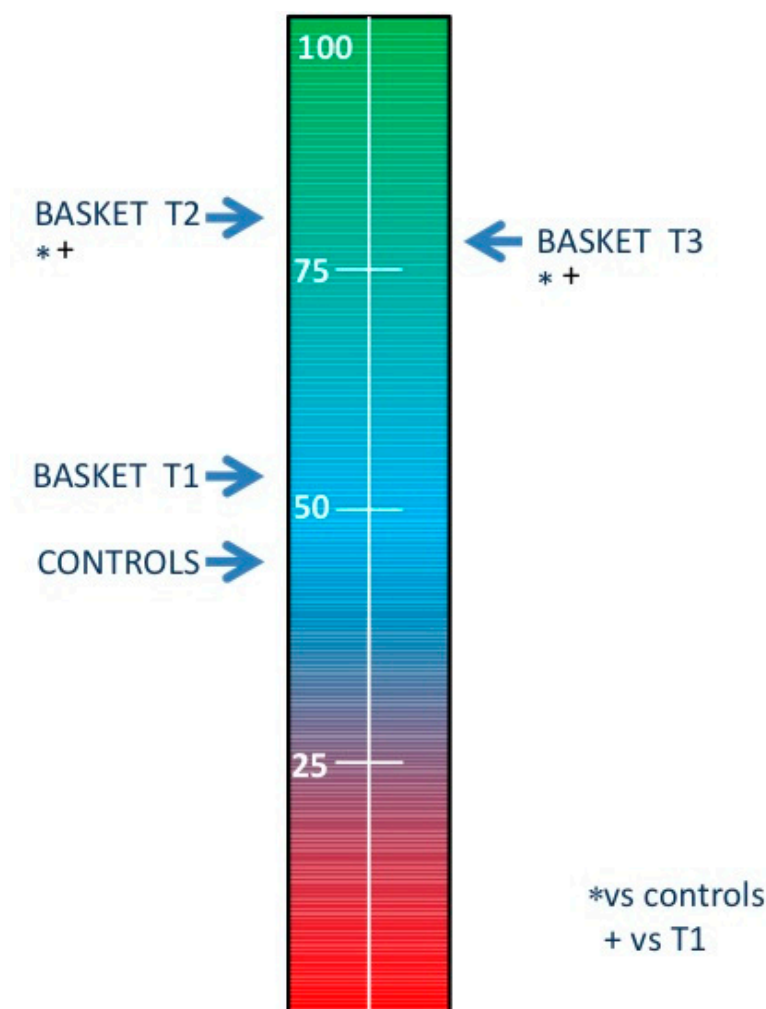
**Abbreviations:** HR, heart rate; RR, RR interval; TP, variance; LFa, Low Frequency spectral component in absolute units; nu, normalized units; HF, High Frequency spectral component; Hz, Hertz; Resp, respiration; K2, squared coherence; Ro, Regularity index; P\_, three beat pattern classification; 4SQ, somatic stress symptoms score. Linear mixed model analysis, with paired contrasts, \* T1 vs. T2; + T1 vs. T3, (SPSS v 26).

It should be remarked that at epoch 1, HR is less than 60 beats/min; RR variance over 5000 msec<sup>2</sup>; the HFnu component is 60, and LF/HF 0.86, overall still clearly depicting the vagal prevalence typical of yearlong intense aerobic training.

This picture is even emphasized after the aerobic training period at the alpine retreat (HR is significantly reduced to 50 beat/min, RR variance increased to more than 8000 msec<sup>2</sup>; HF nu slightly increased to about 64 nu and LF/HF slightly reduced to 0.68).

Resumption of competitions, considering that in this initial period matches were only friendly and not valid for championship points, is not accompanied by significant deviations from the overall picture observed at T2 (e.g., ANSI is 58.83 ± 32.56 at T1;

$81.07 \pm 27.50$ ,  $p = 0.015$  at T2;  $77.44 \pm 26.86$ ,  $p = 0.004$  vs. T1 and  $p = 0.925$  vs. T2) (see Figure 3).



**Figure 3.** Schematic representation of the changes in ANSI levels from T1 to T2 and T3. A nominal value for control normal subjects is also depicted. Significance of contrast is indicated by the symbols in the illustration. (\* vs. T1, + vs. controls).

However a congruent profile of changes is observed with non-linear indices (regularity: RR Ro is  $0.29 \pm 0.10$  at T1, it is  $0.17 \pm 0.08$  at T2,  $p = 0.010$  and does not change [ $p = 0.273$ ] at T3; pattern classification: P<sub>2uv</sub> increases from  $21.23 \pm 11.05$  at T1 to  $36.21 \pm 17.17$ ,  $p = 0.06$  and does not change further at T3  $p = 0.898$  vs. T2; P<sub>0v</sub> has a reverse profile,  $p = 0.028$ ).

Regarding stress symptoms profile it should be remarked that all indices are at T1 at low values (stress  $1.75 \pm 1.82$  au; tiredness  $2.33 \pm 1.30$  au; 4SQ  $14.42 \pm 13.65$  au). Stress and tiredness scores do not vary at T2 or T3; conversely 4SQ is selectively reduce at T2 ( $10.27 \pm 13.08$ ,  $p = 0.014$ ). No changes in respiratory rate are evident (from the T0 value of  $0.250 \pm 0.021$  Hz,  $p = 0.169$ ).

#### 4. Discussion

##### 4.1. Main Findings

This, proof of concept, study on a group of elite basket players clearly shows that ANSI [28], a unitary composite novel index of Autonomic Nervous system regulation, is capable of pinpointing the autonomic changes occurring after few weeks of permanence in an Alpine village for the yearly athletic retreat.



To better appreciate the sustainability value of our findings, particularly in this pandemic period, it may be important to consider that we studied only members of the national Italian basket team, hence by definition we were dealing with a small group of top class national level athletes [42]. Accordingly description of results, mechanistic interpretation and eventual translational consequences are by design selection biased towards excellence. Dealing with elite sports we figured that competition's results depended in addition to the baseline physical training level, also from psychological and ANS preparation [1].

In the present study we observe that linear proxies of cardiac autonomic regulation in the Italian Basketball Team are significantly improved after 2 weeks of permanence in the Alpine retreat (at T2) and following a structured, common training routine. In particular we see that from baseline HR is reduced and RR variance increased, denoting a clear effect on amplitude properties of RR variability [37], which do not change further after the two weeks period of friendly competitions (T3) following the Alpine training retreat. Concomitantly oscillatory indices (LF and HF in nu) do not vary. This dissociation between spectral indices describing physical quantities (that change, see Table 2) or pure numbers (that do not change) occurs also in other conditions, such as after permanence in microgravity [43] and may conceal physiopathological information [35].

ANSI [28], as a combined autonomic biomarker, clearly shows the dynamics of the (likely) shift towards inhibitory (vagal) regulatory settings of the visceral nervous system at T2 (after standardized training) and maintained for the subsequent initial competition season. Of relevance may be the recent observation that ANSI was capable of detecting the differences in ANS regulation that distinguish between playing position in elite football players [9].

Concomitantly changes of non-linear indices of RR variability (Ro, regularity index; and two of the major three beat pattern classifiers) [34] reinforce the interpretation of a vagal shift. This finding suggests that ANSI and other autonomic indices are capable to pinpoint the adaptations to training on top of the already predominant vagal modulation, as can be observed in other specialties like with elite rowers [25]. It should be noted that the group of basket players that we examined presents, as compared to normal subjects, a cardiac autonomic profile largely shifted towards vagal predominance already at entry (T1). (Here we report for convenience the values observed in normal subjects of similar age:  $n = 65$ , age = 22.2 years, HR =  $65.1 \pm 10.7$  b/min; RR TP =  $3970.4 \pm 3504.2$  msec<sup>2</sup>; RR LF/HF =  $2.43 \pm 3.89$ ; ANSI =  $45.5 \pm 27.6$ ) [9]. The vagal predominance over concomitant sympathetic drive is estimated as a 4:1 at rest [44]. Regarding the mechanisms that might underlie this functional shift in addition to an increase in vagal modulation, molecular changes, modifying membrane properties and the funny current of SA activity might play a role [45].

#### 4.2. Interpretation of Autonomic Indices

Interpretation of HRV derived, indirect measures of cardiac autonomic regulation, is still debated in some important aspects [29]. We posit that to a large extent the debate could be resolved considering that the two peripheral autonomic arms (vagal and sympathetic nerves) are not pure efferents (as dictated almost a century ago [46]), but they are part of a complex hierarchical, unitary [47] input-output and positive-negative (sympathetic/parasympathetic) feed-back structure [14,48], connecting target organs with a central autonomic brain [49], in order to match on a beat by beat basis efferent regulatory activity with central command. In addition, interpretation of peripheral signals, like HRV, requires a reasonable appreciation of hidden coding of information, which in this case comprises both amplitude and frequency modalities [20,24]. Interestingly these latter ones are shared across the complete neural path from the central structures [21] to the intermediate level of efferent sympathetic firing and the peripheral end organ oscillations (HRV). Accordingly, as corroborated by multivariate statistics (see Table 3), the distribution of information hidden in HRV should be separately addressed, at least into amplitude, oscillatory, and pulse domains. It may be interesting to note that the greatest latent factor corresponds

to numerical variables (LF and HF nu and LF/HF), while physical variables describe the 2nd and 3rd latent factors (respectively, variance, i.e., amplitude, HR, i.e. pulse). (see for a more detailed discussion [36]). This distributed information may be reassembled into ANSI, a % rank composite index from spectral derived parameters, which has the additional advantage of being built independently from age and gender [28]. ANSI might also profit from the increase of information content likely to be furnished by recombining physical (RR, RR variance) and numerical ( $\Delta$  LFnu) variables [35].

**Table 3.** Exploratory factor analysis with the maximum likelihood extraction method: Rotated factor loadings with the varimax method. Major linear and non-linear indices of HRV.

Total Variance Explained (VAF)					
% of total variance		30.83	28.29	15.82	11.21
cumulative %		30.83	59.13	74.95	86.16
Hidden Factor					
ANS proxies	unit	1	2	3	4
HR	[b/min]			−0.937	
RR Mean	[msec]			0.973	
RR TP	[msec] <sup>2</sup>		0.909		
RR LFa	[msec] <sup>2</sup>		0.839		
RR HFa	[msec] <sup>2</sup>		0.882		
RR LFnu	[nu]	0.967			
RR HFnu	[nu]	−0.982			
RR LF/HF	[.]	0.912			
RR LFHz	[Hz]		0.759		
RR HFHz	[Hz]			−0.460	
RRRo	[.]				0.860
P_0v	[%]				0.921

The remaining non-linear variables (Ro and P\_0v) describe a 4th latent component, also built with numerical variables. Although the variance explained by this factor is small, non-linear indices may as well contribute to a fuller understanding of neural regulation of the SA node.

Stress may also play a significant role in sport, acting as a negative barrier to expected results and modifying neural and non-neural elements of the autonomic response [50]. In the present study we observed two aspects likely to be worth mentioning. First, cognitive stress indices (obtained using the protocol we employ routinely in our clinic) were always in the low range (see e.g., [51]) suggesting that the population of elite athletes participating to the alpine retreat were subjectively well balanced throughout, also after returning to the usual home routine. Conversely, the 4SQ index, which focuses on perception of bodily symptoms, hence being largely independent from cognitive evaluation, indicated a slight, significant reduction of bodily symptom just at the end of the retreat. Subsequently a small increase followed and 4SQ returned towards normal. This selective behavior of 4SQ may depend from a different dynamics of the more “direct” evaluation of bodily symptoms as compared to more “cognitive” evaluation of stress indicators in the face of competitions, as we reported for the Italian rowing team at the Athens Olympic Games [52].

## 5. Conclusions

Sports and exercise play a basic part in everybody’s life either because practice is related to life expectancy and the health burden of several important conditions (from car-

diometabolic to cancer). Accordingly individual monitoring of sport and exercise activity could provide a convenient method to promote an individualized approach to optimization of life style. Numerically, about one on four individuals in Italy practices sports regularly (<https://www.coni.it/it/coni/i-numeri-dello-sport.html>), thereby contributing to the overall section of people that practice physical activity at any level (about 34 million), which implies an important contribution to annual economy ( $\approx 3\%$  GDP).

The present study suggests that modern assessment of cardiac autonomic adjustments to various levels of elite sports training, at least in the specific case of basket, may be achieved employing simple metrics, such as computer analysis of HRV combined with sound underlying physiology and bioengineering. The approach is simple, can be utilized also with actual individual personal electronics and outside of institutional settings and is capable of detecting relatively small changes in ANS regulation, under the assumptions that HRV properties provide information on sports training and individual health. Our study, however, suffers among the limitations, of employing a small population.

HRV has moved also to internet through commercial applications, aimed at millions of practitioners/clients that will require some form of quality control, comprised of health certification. This approach could be as well useful in world health crisis, like the present pandemic, in order to monitor the possible untoward effects of lockdown and activity limitation together with increased personal stress [53].

We conclude with the consideration that in addition to the large interest to HRV indices as markers of training in elite sports, cardiac autonomic evaluation furnishes also a convenient biomarker of individual health. The future is most likely to bring some radical change in relation also to the rapid growth in wearables and the availability of internet approaches that will free users from space and time constraints. HRV, as an easy and simplified metrics of health, intended as capacity of adaptation to the dynamics of own environment, may thus become useful to furnish a personalized window to optimize the sustainability of sport and exercise as contributor to national health.

In the context of elite player performance, ANSI represents a simple, economical and easy to appreciate method to define individually the (%rank) level integrating all linear indicators of CAR. Accordingly it may also be used to derive the effectiveness of sports training programs, whereby the higher % rank ANSI would mean a better state of physical fitness and preparedness for the athletes ahead of a competition.

**Author Contributions:** Conceptualization and methodology: D.L. and L.G.; data curation: M.M.; investigation: D.L., L.G. and M.P.; writing—original draft preparation: D.L.; writing—review and editing: M.C.M.; supervision: M.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Ethics Committee of IRCCS Humanitas Clinical Institute (Rozzano, Italy) on 13 October 2015.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Data will be available on specific request to the authors.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

Abbreviation	Meaning
4SQ	Subjective Stress related Somatic Symptoms
a	Amplitude (usually applied to LF or HF spectral components)
ANSI	Autonomic Nervous System Index
CAR	Cardiac Autonomic Regulation
GPD	Gross domestic product
HF	High Frequency (range from 0.15–0.40 Hz)
HR	Heart Rate
HRV	Heart Rate Variability
Hz	Hertz
K <sup>2</sup>	Square coherence
LF	Low Frequency (range from 0.03–0.14 Hz)
min	minute
msec	millisecond
nu	Normalized units
p	significance
P_0v	Three beat pattern: 0 variation
P_1v	Three beat pattern: 1 variation
P_2lv	Three beat pattern: 2 like variations
P_2uv	Three beat pattern: 2 unlike variations
PSD	Power Spectral Density
rad	Radian (measure of angle; one complete revolution is 2 radians = 360 degrees)
RESP	respiration
RR	Interval between successive peaks of R waves of the ECG
RR VAR	Variance of the continuous RR series
RRRo	Regularity index
RRV	RR interval variability
SD	Standard Deviation
SEM	Standard Error of the Mean
TP	Total spectral power (corresponding to variance)
VAF	Variance Accounted For
VLF	Very Low Frequency
vs	Versus (as compared to)

## References

- Pagani, M.; Lucini, D. Can autonomic monitoring predict results in distance runners? *Am. J. Physiol. Heart Circ. Physiol.* **2009**, *296*, 1721–1722. [[CrossRef](#)]
- Stone, N.M.; Kilding, A.E. Aerobic conditioning for team sport athletes. *Sports Med.* **2009**, *39*, 615–642. [[CrossRef](#)] [[PubMed](#)]
- Thomas, D.T.; Erdman, K.A.; Burke, L.M. American College of Sports Medicine joint position statement. Nutrition and athletic performance. *Med. Sci. Sports Exerc.* **2016**, *48*, 543–568. [[CrossRef](#)]
- Rumbold, J.L.; Fletcher, D.; Daniels, K. A Systematic Review of Stress Management Interventions with Sport Performers. *Sport Exerc. Perform. Psychol.* **2012**, *1*, 173–193. [[CrossRef](#)]
- Hawkins, J.R.; Sharp, E.B.; Williams, S.M. Take a page from your coach's play book: Teaching technical and tactical skills in athletic training. *Athl. Train Educ. J.* **2015**, *102*, 44–248. [[CrossRef](#)]
- Johnson, S.; Wojnar, P.; Price, W.; Foley, T.; Moon, J.; Esposito, E.; Cromartie, F. A coach's responsibility: Learning how to prepare athletes for peak performance. *Sport J.* **2011**, *14*, 1–13.
- Bangsbo, J. Performance in sports—With specific emphasis on the effect of intensified training. *Scand. J. Med. Sci. Sports* **2015**, *25* (Suppl. 4), 88–99. [[CrossRef](#)]
- Mitchell, J.H.; Haskell, W.; Snell, P.; Van Camp, S.P. Task force 8: Classification of sports. *J. Am. Coll. Cardiol.* **2005**, *45*, 1364–1367. [[CrossRef](#)] [[PubMed](#)]
- Lucini, D.; Fallanca, A.; Malacarne, M.; Casasco, M.; Galiuto, L.; Pigozzi, F.; Galanti, G.; Pagani, M. Streamlining analysis of RR interval variability in elite soccer players: Preliminary experience with a composite indicator of cardiac autonomic regulation. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1844. [[CrossRef](#)]
- Saw, A.E.; Main, L.C.; Gustin, P.B. Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *Br. J. Sports Med.* **2016**, *50*, 281–291. [[CrossRef](#)] [[PubMed](#)]

11. Plews, D.J.; Laursen, P.B.; Stanley, J.; Kilding, A.E.; Buchheit, M. Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. *Sports Med.* **2013**, *43*, 773–781. [\[CrossRef\]](#)
12. Buchheit, M. Monitoring training status with HR measures: Do all roads lead to Rome? *Front. Physiol.* **2014**, *5*, 73. [\[CrossRef\]](#)
13. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: Standards of measurement, physiological interpretation and clinical use. *Circulation* **1996**, *93*, 1043–1065. [\[CrossRef\]](#)
14. Malliani, A.; Pagani, M.; Lombardi, F.; Cerutti, S. Cardiovascular neural regulation explored in the frequency domain. *Circulation* **1991**, *84*, 482–492. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Kiviniemi, A.M.; Hautala, A.J.; Kinnunen, H.; Tulppo, M.P. Endurance training guided individually by daily heart rate variability measurements. *Eur. J. Appl. Physiol.* **2007**, *101*, 743–751. [\[CrossRef\]](#)
16. Manzi, V.; Castagna, C.; Padua, E.; Lombardo, M.; D'Ottavio, S.; Massaro, M.; Volterrani, M.; Iellamo, F. Dose-response relationship of autonomic nervous system responses to individualized training impulse in marathon runners. *Am. J. Physiol. Heart Circ. Physiol.* **2009**, *296*, 1733–1740. [\[CrossRef\]](#) [\[PubMed\]](#)
17. Sala, R.; Malacarne, M.; Pagani, M.; Lucini, D. Association between aerobic fitness and indices of autonomic regulation: Cardiovascular risk implications. *J. Sport Med. Phys. Fit.* **2016**, *56*, 794–801.
18. Schmitt, L.; Regnard, J.; Millet, G.P. Monitoring fatigue status with HRV measures in elite athletes: An avenue beyond RMSSD? *Front. Physiol.* **2015**, *6*, 343. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Pagani, M.; Lombardi, F.; Guzzetti, S.; Rimoldi, O.; Furlan, R.; Pizzinelli, P.; Sandrone, G.; Malfatto, G.; Dell'Orto, S.; Piccaluga, E.; et al. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circ. Res.* **1986**, *59*, 178–193. [\[CrossRef\]](#)
20. Pagani, M.; Montano, N.; Porta, A.; Malliani, A.; Abboud, F.M.; Birkett, C.; Somers, V.K. Relationship between spectral components of cardiovascular variabilities and direct measures of muscle sympathetic nerve activity in humans. *Circulation* **1997**, *18*, 1441–1448. [\[CrossRef\]](#)
21. Massimini, M.; Porta, A.; Mariotti, M.; Malliani, A.; Montano, N. Heart rate variability is encoded in the spontaneous discharge of thalamic somatosensory neurones in cat. *J. Physiol.* **2000**, *526*, 387–396. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Cohen, R.A. Yerkes-Dodson Law. In *Encyclopedia of Clinical Neuropsychology*; Springer: New York, NY, USA, 2011; pp. 2737–2738.
23. Aston-Jones, G.; Cohen, J.D. An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annu. Rev. Neurosci.* **2005**, *28*, 403–450. [\[CrossRef\]](#)
24. Pagani, M.; Malliani, A. Interpreting oscillations of muscle sympathetic nerve activity and heart rate variability. *J. Hypertens.* **2000**, *18*, 1709–1719. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Iellamo, F.; Legramante, J.M.; Pigozzi, F.; Spataro, A.; Norbiato, G.; Lucini, D.; Pagani, M. Conversion from vagal to sympathetic predominance with strenuous training in high-performance world class athletes. *Circulation* **2002**, *105*, 2719–2724. [\[CrossRef\]](#)
26. Sandercock, G.R.H.; Brodie, D.A. The use of heart rate variability measures to assess autonomic control during exercise. *Scand. J. Med. Sci. Sports* **2006**, *16*, 302–313. [\[CrossRef\]](#)
27. Sala, R.; Malacarne, M.; Tosi, F.; Benzi, M.; Solaro, N.; Tamorri, S.; Spataro, A.; Pagani, M.; Lucini, D. May a unitary autonomic index help assess autonomic cardiac regulation in elite athletes? Preliminary observations on the national Italian Olympic committee team. *J. Sport Med. Phys. Fit.* **2017**, *57*, 1702–1710. [\[CrossRef\]](#)
28. Sala, R.; Malacarne, M.; Solaro, N.; Pagani, M.; Lucini, D. A composite autonomic index as unitary metric for heart rate variability: A proof of concept. *Eur. J. Clin. Investig.* **2017**, *47*, 241–249. [\[CrossRef\]](#)
29. Pagani, M.; Sala, R.; Malacarne, M.; Lucini, D. Benchmarking heart rate variability to overcome sex-related bias. *Adv. Exp. Med. Biol.* **2018**, *1065*, 191–205. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Lucini, D.; Sala, R.; Spataro, A.; Malacarne, M.; Benzi, M.; Tamorri, S.; Pagani, M. Can the use of a single integrated unitary autonomic index provide early clues for eventual eligibility for Olympic games? *Eur. J. Appl. Physiol.* **2018**, *118*, 919–926. [\[CrossRef\]](#)
31. Oggionni, G.; Spataro, A.; Pelliccia, A.; Malacarne, M.; Pagani, M.; Lucini, D. Left ventricular hypertrophy in world class elite athletes is associated with signs of improved cardiac autonomic regulation. *Eur. J. Prev. Cardiol.* **2019**. [\[CrossRef\]](#)
32. Lucini, D.; Malacarne, M.; Gatzemeier, W.; Pagani, M. A simple home-based lifestyle intervention program to improve cardiac autonomic regulation in patients with increased cardiometabolic risk. *Sustainability* **2020**, *12*, 7671. [\[CrossRef\]](#)
33. Lucini, D.; Malacarne, M.; Oggionni, G.; Gatzmeier, W.; Santoro, A.; Pagani, M. Endocrine adjuvant therapy might impair cardiac autonomic regulation in breast cancer survivors. *J. Cardiovasc. Med.* **2019**, *3*, 34–49. [\[CrossRef\]](#)
34. Porta, A.; Guzzetti, S.; Montano, N.; Furlan, R.; Pagani, M.; Malliani, A.; Cerutti, S. Entropy, entropy rate, and pattern classification as tools to typify complexity in short heart period variability series. *IEEE Trans. Biomed. Eng.* **2001**, *48*, 1282–1291. [\[CrossRef\]](#)
35. Kerkhof, P.L.M.; Peace, R.A.; Handly, N. Ratiology and a complementary class of metrics for cardiovascular investigations. *Physiology* **2019**, *34*, 250–263. [\[CrossRef\]](#) [\[PubMed\]](#)
36. Lucini, D.; Solaro, N.; Pagani, M. Autonomic differentiation map: A novel statistical tool for interpretation of Heart Rate Variability. *Front. Physiol.* **2018**, *9*, 1–13. [\[CrossRef\]](#) [\[PubMed\]](#)
37. Solaro, N.; Malacarne, M.; Pagani, M.; Lucini, D. Cardiac baroreflex, HRV, and statistics: An interdisciplinary approach in hypertension. *Front. Physiol.* **2019**, *10*, 478. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Badilini, F.; Pagani, M.; Porta, A. HeartScope: A software tool addressing autonomic nervous system regulation. *Comput. Cardiol.* **2005**, *32*, 259–262. [\[CrossRef\]](#)



39. Lucini, D.; Marchetti, I.; Spataro, A.; Malacarne, M.; Benzi, M.; Tamorri, S.; Sala, R.; Pagani, M. Heart rate variability to monitor performance in elite athletes: Criticalities and avoidable pitfalls. *Int. J. Cardiol.* **2017**, *240*, 307–312. [CrossRef]
40. West, B.T. Analyzing longitudinal data with the linear mixed models procedure in SPSS. *Eval. Health Prof.* **2009**, *32*, 207–228. [CrossRef]
41. IBM. Linear Mixed-Effects Modeling in SPSS: An Introduction to the MIXED Procedure. Available online: [https://www.spss.ch/upload/1126184451\\_Linear%20Mixed%20Effects%20Modeling%20in%20SPSS.pdf](https://www.spss.ch/upload/1126184451_Linear%20Mixed%20Effects%20Modeling%20in%20SPSS.pdf) (accessed on 17 February 2021).
42. Pawelczyk, J.A. Big concepts, small N. *J. Physiol.* **2006**, *572*, 607–608. [CrossRef]
43. Ferretti, G.; Iellamo, F.; Pizzinelli, P.; Kenfack, M.A.; Lador, F.; Lucini, D.; Porta, A.; Narkiewicz, K.; Pagani, M. Prolonged head down bed rest-induced inactivity impairs tonic autonomic regulation while sparing oscillatory cardiovascular rhythms in healthy humans. *J. Hypertens.* **2009**, *27*, 551–561. [CrossRef]
44. White, D.W.; Raven, P.B. Autonomic neural control of heart rate during dynamic exercise: Revisited. *J. Physiol.* **2014**, *592*, 2491–2500. [CrossRef]
45. D'souza, A.; Bucci, A.; Johnsen, A.B.; Logantha, S.J.R.J.; Monfredi, O.; Yanni, J.; Prehar, S.; Hart, G.; Cartwright, E.; Wisloff, U.; et al. Exercise training reduces resting heart rate via downregulation of the funny channel HCN4. *Nat. Commun.* **2014**, *5*, 3775. [CrossRef] [PubMed]
46. Langley, J. *The Autonomic Nervous System*; Heffer & Sons: Cambridge, UK, 1921.
47. Hess, W.R. The central control of the activity of internal organs. In Proceedings of the Nobel Lecture Physiology or Medicine, Stockholm, Sweden, 12 December 1949; Elsevier Publishing Company: Amsterdam, The Netherlands, 1964; pp. 1942–1962. Available online: <https://www.nobelprize.org/prizes/medicine/1949/hess/lecture/> (accessed on 17 February 2021).
48. Fukuda, K.; Kanazawa, H.; Aizawa, Y.; Ardell, J.L.; Shivkumar, K. Cardiac innervation and sudden cardiac death. *Circ. Res.* **2015**, *116*, 2005–2019. [CrossRef] [PubMed]
49. Benarroch, E.E. The central autonomic network: Functional organization, dysfunction, and perspective. *Mayo Clin. Proc.* **1993**, *68*, 988–1001. [CrossRef]
50. Iellamo, F.; Pigozzi, F.; Parisi, A.; Di Salvo, V.; Vago, T.; Norbiato, G.; Lucini, D.; Pagani, M. The stress of competition dissociates neural and cortisol homeostasis in elite athletes. *J. Sport Med. Phys. Fit.* **2003**, *43*, 539–545.
51. Lucini, D.; Solaro, N.; Lesma, A.; Gillet, V.B.; Pagani, M. Health promotion in the workplace: Assessing stress and lifestyle with an intranet tool. *J. Med. Internet Res.* **2011**, *13*, e88. [CrossRef]
52. Iellamo, F.; Pigozzi, F.; Spataro, A.; Di Salvo, V.; Fagnani, F.; Roselli, A.; Rizzo, M.; Malacarne, M.; Pagani, M.; Lucini, D. Autonomic and psychological adaptation in Olympic rowers. *J. Sport. Med. Phys. Fit.* **2006**, *46*, 598–604.
53. Di Cagno, A.; Buonsenso, A.; Baralla, F.; Grazioli, E.; Di Martino, G.; Lecce, E.; Calcagno, G.; Fiorilli, G. Psychological impact of the quarantine-induced stress during the coronavirus (COVID-19) outbreak among Italian athletes. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8867. [CrossRef]