Can the use of a single integrated unitary autonomic index provide early clues for eventual eligibility for olympic games?

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Received: 24 October 2017 / Accepted: 6 February 2018

Abstract

Purpose

Optimal autonomic regulation and stress resilience might be considered critical elements of athletic performance. We hypothesize that a novel unitary autonomic index for sports (ANSIs), together with a somatic stress related symptom score (4SQ) might help characterize athletes who were eventually selected for the Rio 2016 Olympic Games Italian team (Rio +).

Methods

In this retrospective study we examined 778 athletes (age 24.4 ± 6.7 yrs) who underwent a planned yearly pre-participation screening. All athletes underwent clinical, autonomic and exercise ECG evaluation. The combination of vagal and sympathetic indices from RR variability into ANSIs was performed by radar plot and percent ranking of index variables. We assessed (Rio +) versus (Rio −) athletes also after subdivision into three sport intensity groups (low, mid and high intensity).

Results

Overall there were no significant differences between (Rio +) and (Rio −) athletes when considering individual spectral derived variables. Conversely, the unitary Index ANSIs was significantly higher in (Rio +) compared to (Rio −) athletes (respectively 54.5 ± 29.5 and 47.9 ± 28.4 $p = 0.014$). This difference was particularly evident ($p = 0.017$) in the group of athletes characterized by both high static and dynamic components. 4SQ was smaller in the (Rio +) group, particularly in the groups of athletes characterized by both low-medium static and dynamic components.

Conclusions

ANSIs, a proxy of integrated cardiac autonomic regulation and simple assessment of resilience to stress, may differentiate Italian athletes who

were eventually selected for participation in the 2016 Rio Olympic Games from those who were not, suggesting the possibility of a "winning functional phenotype".

Keywords

Olympic Games
Elite athletes
Autonomic nervous system
Stress resilience

Abbreviations

4SQ	Somatic Stress Related Symptom Score
a.m	Morning
A.U.	Arbitrary units
ANS	Autonomic nervous system
ANSI	Unitary multivariate percent ranked ANS index
ANSIs	Unitary autonomic index for sports
AR	Autoregressive
BMI	Body mass index
CM5	ECG chest lead
CONI	Italian national olympic committee
DC	Deceleration capacity
e.g.	For example
ECG	Electrocardiogram
HF	High frequency
HRV	Heart rate variability
J-T	Jonckheere terpstra
LF	Low frequency
nu	Normalized units
PC	Personal computer
RRV	RR Interval variability

SD	Standard deviation
SPSS	Statistical package for the social sciences
Δ	Difference

Communicated by Keith Phillip George.

Electronic supplementary material

The online version of this article (https://doi.org/10.1007/s00421-018-3822-2) contains supplementary material, which is available to authorized users.

Introduction

In the world of sports Olympic Games occupy a special place, justifying the magnitude of personal and institutional investments put forth in order of reaching with victory the much sought gold medal, signaling the uniqueness of the result. Among the elements which contribute to athletes' performance, autonomic nervous system (ANS) may play a role that is attracting attention.

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The recent development of simplified instrumentation and software tools brought to the interest of athletes and coaches the utilization of Heart Rate Variability (HRV) (Buchheit 2014; Plews et al. 2013) to estimate the autonomic component of training as a possible additional aid. In fact, it is well known that trained athletes display a lower resting HR (Smith et al. 1989), whose origin can be traced to either ion channel remodeling of sinus node (D'Souza et al. 2014) or to increased vagal tone (White and Raven 2014), (or a combination), thought to represent a favorable condition. HRV could thus be used to assess the complex dynamic of autonomic adaptation (Buchheit 2014), which in winners seems to oscillate from vagal predominance during moderate intensity training and shift into prevailing sympathetic modulation just at the time of competition (Iellamo et al. 2002). Moreover aerobic training may ameliorate ANS profile in patients with cardiometabolic diseases such as Ischemic heart diseases (Iellamo et al. 2000; La Rovere et al. 1998; Lucini et al. 2002), hypertension (Pagani et al. 1988) and diabetes (Lucini et al. 2013).

However the assessment of HRV (or rather RR V) is still far from perfect, particularly from the users' point of view. In fact there are several unresolved operational aspects regarding protocols, methodology, accuracy and reliability (Sassi et al. 2015). In particular it is debated whether to prefer short (few minutes) or long (24 h) data series, to use time or frequency domain algorithms, to consider raw or normalized units, and which of the several variables derived from the RR V signal we should focus, and why. This latter concept might assume particular importance when HRV is employed to estimate autonomic component in elite training: For instance time domain indexes, like total variance, are accepted as monitors of possible increases in vagal modulation associated to moderate aerobic training (Plews et al. 2013), while this index might however be less reliable if we want to detect ANS responses to excitatory stimuli (Sala et al. 2016) as during standing up.

Furthermore available applications usually measure Heart Rate (not through ECG), disregarding the 10% possibility of error (Lucini et al. 2017) deriving from not verifying the sinus nature of the tachogram or respiratory frequency.

All these critical aspects hinder the usage of HRV as clinical tool to estimate autonomic component of training.

To overcome, some of these barriers, we proposed(Sala et al. 2017a) that a unitary autonomic nervous system index of cardiac regulation (ANSI), as furnished by a radar plot (Saary 2008), considering simultaneously the most informative spectral variables, could provide an easier appreciation of overall autonomic performance, solving the riddle introduced by numerous variables and novel techniques emphasizing the integrated nature of central and peripheral neural regulation (Okano et al. 2015), and simplifying interpretation of findings. We proposed to outdo raw values of individual indices, and condense the overall information (Haken 1977) about performance of cardiac autonomic regulation into a unitary multivariate percent ranked ANS index computed from the pooled values from a reference population (ANSI). In clinical applications (Sala et al. 2017a) ANSI is computed from three indices (RR interval, RR variance and rest-stand difference of the low frequency, i.e., LF, component of RR variability in normalized units, nu), which carry the major part (> 80%) of both tonic and oscillatory information embedded in HRV (considering both rest and standing up). By design ANSI results insensitive to gender and age bias.

This Index was extended to sports (ANSIs) considering in its construction also parameters derived from recovery of exercise to better represent the dynamics of autonomic regulation in elite athletes (Sala et al. 2017b). ANSIs provide information (Haken 1977) about the improvement in autonomic performance occurring with increasing work-loads in the Olympic specialty from archery to cycling or rowing.

The present investigation was made possible by the unique yearly pre-participation health screening which is undertaken well in advance of the Olympic Games by all top Italian athletes in the Rome facilities of the Italian National Olympic Committee (CONI).

Aim of this study was to assess whether ANSIs, a percent ranked unitary index, proxy of overall autonomic regulation, may differentiate the population of elite athletes who were selected to participate in the 2016 Rio Olympic Games from the group who was not.

In view of the important complementary role of psychological factors in determining competition performance, as, e.g., Iellamo et al. (2006) showed for the Athens Olympic games, we test if self-reported indices of somatic stress related symptoms are lower in the (Rio +) group.

Methods

This study involved 778 (475 males and 303 females) (age 24.4 ± 6.7 years, minimum 16 yrs maximum 59 years) elite athletes who took part in the selection procedure for the 2016 Rio Olympic Games for the National Italian Olympic Committee (CONI). General anthropometric characteristics are presented in Table 1.

AQ3

Table 1

Descriptive statistics of anthropometric data of Selected (Rio +) or Unselected (Rio −) Athletes for Olympic Games of Rio 2016

	(Rio −)	**(Rio +)**	
	N 540	**N 238**	***p* value**
	Mean ± SD	**Mean ± SD**	
Age (year)	23.49 ± 7.08	26.48 ± 5.10	< **0.001**
HR (Bpm)	60.42 ± 10.10	57.73 ± 9.54	**0.001**
SAP (mmHg)	118.71 ± 13.75	117.71 ± 12.90	0.338
DAP (mmHg)	64.80 ± 8.62	65.35 ± 7.68	0.395
Weight (kg)	72.52 ± 13.41	72.59 ± 14.92	0.947
Height (cm)	178.06 ± 10.61	178.11 ± 10.83	0.949
BMI	22.75 ± 2.91	22.67 ± 2.96	0.740

HR heart rate, *SAP* systolic arterial pressure, *DAP* diastolic arterial pressure, *BMI* body mass index

As part of the selection procedure all athletes underwent a complete history and clinical evaluation which included (1) a rest and stand indirect autonomic assessment, by way of autoregressive (AR) spectral analysis of RR Variability (Pagani et al. 1986), (2) a standardized symptom limited incremental bicycle ECG stress test and (3) a subjective stress symptoms profile determination with a self-report questionnaire that we already used during the preparation for the Athens Olympic Games (Iellamo et al. 2006).

This procedure took place 352 ± 253 days before the Rio Olympic Games and 7.5 ± 21.4 days after last full load training session, at the Institute of Medicine and Sports Science, CONI, Rome. All individuals participating in this study were cleared for active sports participation, and were thus free from evidence of diseases or disturbances that could interfere with results.

This study followed the principles of Declaration of Helsinki and Title 45, US Code of Federal Regulations, Part 46, Protection of Human Subjects, Revised November 13, 2001, effective December 13, 2001 and was cleared by local Institutional Science Committee (Istituto Medicina e Scienza dello Sport, Roma) and by local Ethics Committee (ASL Roma/A). All subjects gave their written informed consent.

Protocol

Subjects arrived at the clinic between 9.00 and 12.00 a.m., at least 2 h after eating a light breakfast. After the initial clinical assessment, they underwent an autonomic evaluation, followed by the bicycle exercise test (see above).

Autonomic assessment

Rest domain

All subjects were requested to avoid caffeinated beverages since waking and to keep physical training in the preceding 24 h within intermediate levels. After a preliminary 10-min rest period in the supine position which allowed for stabilization and sensors placements, an ECG, arterial pressure waveforms (Finometer, TNO, NL) and respiratory activity were continuously recorded over a 5-min period. The ECG (CM5) and the respiratory signal were obtained with a two-way radiotelemetry system (Marazza, Monza Italy). Data were acquired with a PC at 250 samples/channel/second using a parabolic interpolation to improve R peak detection accuracy. As previously described (Pagani et al. 1986), we employ a custom software (Heart Scope) (Badilini et al. 2005) to perform autoregressive spectral analysis of RR Variability, which provides proxies of parasympathetic cardiac regulation such as the RR total power and High

Frequency (HF) component, in nu. Spectral analysis was also performed on uncalibrated respiratory waveform to ensure that HF component was synchronous with the major respiratory oscillations, and exclude entrainment (Lucini et al. 2017).

Stand domain

The difference (Δ) between stand and rest powers in nu of Low Frequency (LF) component provides estimates of the sympathetic excitatory response to standing up (additional 5 min), inducing a leftward shift in the LF-HF autonomic balance (Pagani et al. 1986).

Exercise domain

The medical procedure comprised a standardized incremental bicycle ergometer test with a duration set at about 8–12 min, which is always performed after HRV data acquisition. The quantification of the ECG derived RR dynamics of the recovery from exercise for each individual was performed with an ad hoc software (DynaScope) (Toninelli et al. 2012), which provides the following vagal related indices: initial slope of the RR recovery curve (Brady Slope), and Deceleration Capacity index (DC) (Bauer et al. 2006).

Considering the sympathetic-parasympathetic antagonistic dynamic within the “unbroken” unitary purpose of neural visceral regulation (Hess W R 1949), i.e., vagal predominance at rest (White and Raven 2014), sympathetic predominance during standing up (Pagani et al. 1986) and vagal reactivation (Imai et al. 1994) combined with sympathetic excitation during recovery from exercise (Pecanha et al. 2017), we introduced (Sala et al. 2017b) a unitary Autonomic Nervous System Index for sports (ANSIs). ANSIs is built as a radar plot synthesis of a set of variables likely to individually contribute to different significant elements of information about overall autonomic regulation in sports and thus identified with the proxies of RR interval (Katona and Jih 1975), RR variance (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996), HF nu (Pagani et al. 1986), from the rest domain, Δ LF nu as an index of excitatory orthostatic responsiveness from the stand domain (Lucini et al. 2014a) as well as brady slope (Lucini et al. 2014b) and Deceleration Capacity (Bauer et al. 2006) as vagal reactivation in the face of hightened sympathetic drive from the exercise domain.

Somatic stress symptoms evaluation

As in a prior study (Iellamo et al. 2006), all subjects completed a self-administered questionnaire that focused on: (i) the appraisal of overall stress and (ii) fatigue perception by Likert linear scales from 0 ('no perception') to 10 ('highest perception'); (iii). The Subjective Stress-related Somatic Symptoms Questionnaire (4S-Q), inquiring about 18 somatic symptoms accounting for the majority of somatic complaints. For scoring purpose, responses were coded from 0 ('no feeling') to 10 ('a strong feeling'), thus the total score ranged from 0 to 180.

Sports category

To account for the different absolute physical activity load according to specific sports specialties we attributed every athlete to one of three groups, according to the combined intensity (low, moderate, high) of static and dynamic components, further simplifying the approach initially suggested by Mitchell et al. (2005).

Statistics

Data in text and tables are presented as means ± standard deviation (SD). Significance of the differences between athletes selected (Rio +) and non-selected (Rio −) for Rio 2016 was assessed by unpaired *t* test and Bonferroni correction; significant trends were assessed using the J-T test. In addition a binomial logistic regression was employed to assess relative significance of contribution of autonomic and stress indices. Computations were performed employing a commercial package (SPSS version 23) and significance was set at $p < 0.05$.

Results

(Rio +) athletes are slightly older than (Rio −) athletes and present a slightly lower heart rate. There are no differences with regards to arterial pressure and BMI (Table 1).

Autonomic nervous system variables

RR interval values and main autonomic nervous system parameters derived from autoregressive spectral analysis are reported in Table 2.

Table 2

Descriptive statistics of Autonomic variables of Selected (Rio +) or Unselected (Rio−) Athletes for Olympic Games of Rio 2016

	(Rio −)	**(Rio +)**	***p* value**
	N 494	**N 220**	
	Mean ± SD	**Mean ± SD**	
RR mean (ms)	1020.6 ± 170.0	1067.3 ± 174.1	**0.001**
TP (ms^2)	4899.8 ± 4541.7	4555.3 ± 3547.8	0.319
LF (ms^2)	1157.8 ± 1165.3	1000.7 ± 900.5	0.076
HF (ms^2)	2070.2 ± 2978.9	1842.9 ± 2185.5	0.310
LF (nu)	41.2 ± 20.1	38.4 ± 21.0	0.086
HF (nu)	53.7 ± 20.3	56.2 ± 21.9	0.135
Δ LF (nu)	40.5 ± 20.8	42.0 ± 23.0	0.407
LF/HF	1.2 ± 1.7	1.3 ± 2.2	0.905
Brady slope (ms/s)	1.9 ± 1.0	2.1 ± 1.1	**0.010**
DC (ms)	3.2 ± 1.4	3.7 ± 1.7	< **0.001**

RR RR interval, *TP* total power of RR variability, *LF* low frequency component of RR variability, *HF* high frequency component of RR variability, *nu* normalized unit, Δ *LF* stand-rest difference of low frequency component of RR variability, *DC* deceleration capacity

Overall, except a slightly longer RR interval, there are no significant differences between (Rio +) and (Rio −) athletes. This lack of significant differences between (Rio +) and (Rio −) athletes was also present when considering the three different groups according to absolute training load characterizing specific sports specialties (see table in online appendix).

Indices of RR recovery after exercise

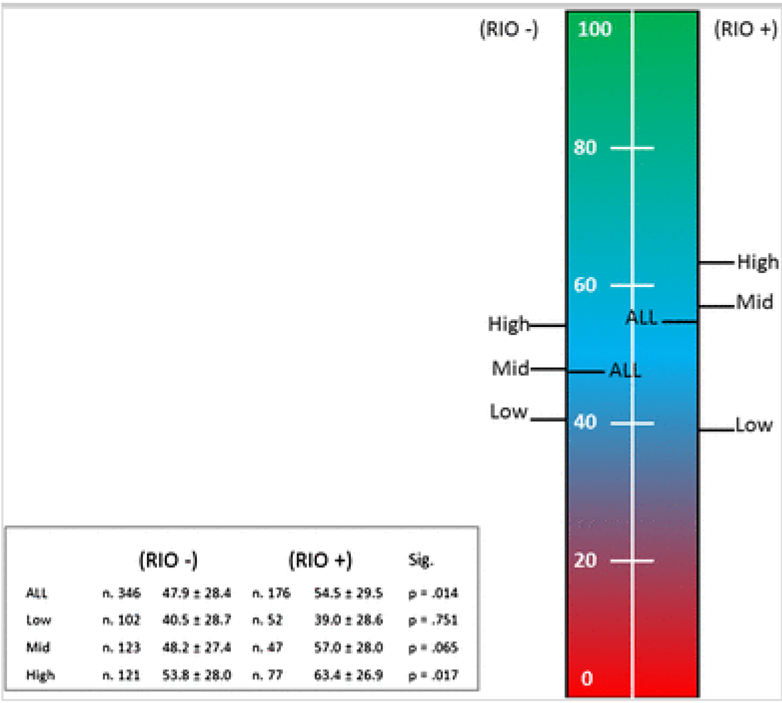
Table 2 also reports values of brady slope and DC that are significantly higher in (Rio +) athletes. This difference is selectively observed in moderate and high intensity groups (see table in online appendix), and is absent in the low intensity groups.

ANSIs

The Index ANSIs, a unitary proxy of overall autonomic regulation for sports, with the capacity to investigate the individual response to training, is significantly higher in (Rio +) athletes compared to (Rio −) athletes (respectively 54.5 ± 29.5 and 47.9 ± 28.4, $p = 0.014$). This difference is particularly evident ($p = 0.017$) in the group of athletes characterized by both high static and dynamic components (Fig. 1). Borderline significance ($p = 0.065$) is observed in the moderate intensity group and no difference ($p = 0.751$) in the low intensity group, suggesting a progression of the ANS role as sports intensity load increases (J-T test < 0.001 both in (Rio +) and (Rio −) groups) as well as a potential capacity to follow the daily changes in work-loads typical of routine, long term training.

Fig. 1

Graphical representation of the mean value of percentile rank of ANSIs for the global group of athletes (inside of calibration bar, ALL) who were eventually selected for participating to 2016 Rio Olympic Games [right, (Rio +)] and of those who were not [left, (Rio −)]. Data from the same population, subdivided according to intensity of sport related activity (Low intensity, Mid intensity and High intensity subgroups) is shown outside the calibration bar. Values of the subgroups that were eventually selected for RIO (Rio +) are indicated on the right side, while those of the subgroups that were not selected (Rio -) are indicated on the left side. A 0–100 reference scale (white) is provided in the bar. Significance of differences between pairs of subgroups [(Rio +) vs (Rio −)] is indicated in the bottom left table



Somatic stress symptoms

The overall self-reported level of subjective stress was low for both groups, and slightly less in the (Rio +) group than in the (Rio −) (2.3 ± 2.5 versus 2.7 ± 2.6, $p = 0.046$). This difference was clearer for the somatic symptoms index 4SQ (17.0 ± 19.8 vs. 22.6 ± 22.1, $p = 0.001$). Considering separately the three sport groups, 4SQ was significantly more elevated in the (Rio-) group of athletes competing in specialties with low or medium intensity activity levels (low intensity: 22.9 ± 22.8 versus 15.7 ± 16.6, $p = 0.023$; Middle intensity: 22.4 ± 20.0 vs 15.76 ± 18.8, $p = 0.016$), no difference being observed in the High intensity groups.

Discussion

Present data obtained far in advance of the Rio 2016 Olympic Games show that simple integrated metrics of cardiac autonomic regulation, based on a multivariate percent ranked unitary index (Sala et al. 2017a, b) from RR variability derived autonomic proxies, and simple assessment of resilience to stress (Iellamo et al. 2006; Lucini et al. 2005a, b), may differentiate Italian athletes who were eventually selected to participate in the 2016 Rio Olympic Games from those who were not. The simultaneous observation that (Rio +) athletes show a better somatic stress symptoms profile suggests the possibility that the brain (Okano et al. 2015) might underscore a sort of "winning functional phenotype".

This investigation builds on the concept that athletic performance (hence competitions' results) largely depends on a series of interacting elements: fitness (particularly aerobic) (Coyle 1999; Lorenz et al. 2013), autonomic (particularly vagal) regulation (Aubert et al. 2003; Chalencon et al. 2015) and resilience to stress (Iellamo et al. 2006; Lazarus 2000; Pagani and Lucini 2009), undescoring the contemporary role attributed to the brain (Okano et al. 2015).

In this study we focused on:

1. The role played by autonomic regulation of cardiorespiratory dynamics, particularly the vagal arm, and the overall performance of ANS regulation.
2. The role of resilience to stress as a critical element of elite athletic performance.

Autonomic regulation

There is a growing interest in the introduction of ANS evaluation in the routine management of athletic practice (Iellamo et al. 2006; Plews et al. 2013; Sala et al. 2017b), because of a potentially important role in the complex dynamics of training. Specifically,

- intermediate levels of training loads are associated with signs of increased vagal drive (Iellamo et al. 2002; Smith et al. 1989)

- intense training volumes, which occur close to competitions, are characterized by a more complex picture that may include sympathetic activation (Iellamo et al. 2002; Manzi et al. 2009)
- changes in autonomic indices may foretell daily performance (Chalencon et al. 2015) hence help manage practical aspects of routine training.

However there are barriers to a simple practical use: e.g., there is incomplete consensus regarding methodologies and interpretation of metrics derived from ANS assessment (Buchheit 2014; Sala et al. 2016). This might result from the observation that specific techniques might be better suited to different conditions, thus limiting consistency of findings in the multiplicity of real life settings. For instance, if the goal is to trace long term, basal autonomic effects of endurance training, the simpler RR variability measures (variance or SD, or even just RR interval) may be selected (considering that other indices, HF or baroreflex gain, may also confirm vagal predominance) (Kiviniemi et al. 2014). Conversely, if the goal is to assess the subtler time-varying effects of training on the autonomic excitatory balance, which might predict performance at the time of competition, then normalized oscillatory components of RR variability might be more appropriate (Iellamo et al. 2002; Sala et al. 2016). HR recovery (Pecanha et al. 2017) might specifically describe the reactivation of parasympathetic tone in the face of post-exercise elevated sympathetic drive (Coote 2010). Finally, in the eventual possibility of introducing ANS regulation in the daily training routines, simplicity of methods and reliability of results is of paramount importance for both coaches and athletes.

In the present study the use of an integrated autonomic index for sports (Sala et al. 2017b) (ANSIs) enjoys the simplicity of a single value assessing individuals against the entire population as a pooled benchmark. Accordingly (nominally) all autonomic information (distributed through many derived indices) (Haken 1983) can be exploited simultaneously, avoiding the still unresolved debates about which HRV variables might be best to employ, hence opening a novel window towards a wider use of ANS assessment in real life settings, and in particular to monitor routine athletes performances. In this case it should be recalled that ANSIs integrates in a single determination various (linear) aspects of RRV, thus (in principle) largely simplifying practical aspects of frequent evaluation.

Resilience to stress

Resilience to stress (and emotions) is a critical element of elite athletic performance (Lazarus 2000; Schinke et al. 2012; Woodman and Hardy 2003). Emotional struggles, or decreased motivation when facing difficulties, may interfere with attention and concentration, which are both essential elements for top performance (Lazarus 2000).

To address this aspect we simply focus (Iellamo et al. 2006; Lucini et al. 2005a, b) on subjective perception of stress and on stress derived somatic symptoms perception, avoiding the use of more complex (hence time consuming) questionnaires which also might involve breach of privacy, e.g., by revealing personal thoughts that some athletes may not desire to disclose, particularly when their participation in the Olympic Games is under evaluation. The potential importance of the perceived stress level in predicting Olympic Games performance was highlighted by a previous investigation showing that at midseason during a year of training for the 2004 Athens Games the reported stress level of the Italian rowing team was less for those athletes who eventually won a medal (Iellamo et al. 2006). In the present study, we observe a reduced perception of stress and of somatic symptoms in (Rio +) athletes. This difference was more apparent in those athletes who performed disciplines characterized by low and medium static and dynamic components, where attention and concentration play a greater role (Mahoney et al. 1987).

Our data seem to suggest that autonomic regulation and resilience to stress are, both, functional elements capable of influencing athletic performance, the latter one being preeminent in disciplines where attention and concentration are of paramount importance, while autonomic regulation better reflects the effects of high intensity (both static and dynamic) training. This contention seems supported by binomial logistic regression analysis, showing that both ANSIs and 4SQ significantly (respectively, p = 0.045 and = 0.019) contribute to the (Rio +) and (Rio-) differentiation model, being this effect more apparent in lower intensity specialties (see Fig. 1).

Overall, athletic performance could be described as the perfect, timely blend of athletic fitness, cardiac autonomic balance and psychological resilience (Pagani and Lucini 2009). The higher values of autonomic performance index and reduced subjective stress symptoms shown by our data in athletes who were eventually selected for the Olympic team, could also be interpreted as an ideal athletic phenotype capable of integrating stress and emotions with autonomic settings, as reflected by ANSIs, following the novel paradigm contemplating a crucial role played by the brain in regulating performance (Okano et al. 2015). Notably, ANSIs integrates parasympathetic elements (resting HF, and RR recovery after exercise) with ΔLFnu as a proxy of excitatory sympathetic responsiveness providing a single value for the fundamentally "unbroken" unitary purpose of neural visceral regulation (Hess 1949). Optimal values of ANSIs and stress could provide unprecedented information useful for behavior management and training for elite performance.

Recommendations for future studies

This is essentially a retrospective study, with a prospective design. Recordings were performed before the Olympic Games but attribution to Rio Group was necessarily made after recordings. Furthermore the study is based on indirect autonomic and subjective indices. It would have been outside the goals of a practical investigation to aim for direct measures of autonomic involvement (e.g., with electroneurography).

The study builds on the CONI sponsored yearly pre-participation screening that renders it unique and non-reproducible. Accordingly some pragmatic (Ford and Norrie 2016) limitations on the protocol had to be accepted: in future studies it would be advisable not only to obtain frequent, repeated recordings, but also to obtain exact measures of training loads in this specific population comprising very different sport specialties. Considering self-reports of percent training intensity all subjects declared an intermediate load [(Rio +) 70.6 ± 19.5% and (Rio −) 71.3 ± 18.6%, p = 0.065], i.e., a condition considered to avoid sympathetic prevalence (Iellamo et al. 2002). The level of reported fatigue perception was also low [(Rio +) 3.0 ± 2.6A.U. and (Rio −) 3.3 ± 2.6 A.U., p = 0.089], and within values observed in other studies away from competitions (Iellamo et al. 2006). In brief it would be most important to demonstrate that the index ANSIs as a tool is easy to use and accurate, and thus could be used by coaches routinely. Finally, it would be helpful to determine strength and weaknesses of ANSIs as compared to other indices, such as RR variance, or RR recovery. Let's just point out that (Table 2) clearly shows that RR variance is not capable of showing differences between Rio + and Rio- groups. The available information, although suggestive, cannot support however final judgments about possible superiority of an index versus other ones.

Conclusions

In conclusion our study provides a new, non-invasive, integrated autonomic index for sports (ANSIs), which could help monitoring training status and performance in athletes, also favoring athletes' management, especially if combined with stress symptoms assessment. In elite athletes it might also provide some early clues about eventual eligibility for Olympic Games.

Acknowledgements

We would like to thank Dana Alon Shiffer (LA, CA, USA) for mother tongue language and English style assistance.

Compliance with ethical standards

Conflict of interest Authors declare that they have no conflict of interest.

Electronic supplementary material

Below is the link to the electronic supplementary material.

Supplementary material 1 (DOC 83 KB)

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Significance of differences between pairs of subgroups ((Rio +) vs (Rio -)) is indicated in the bottom left table

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