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Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness

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Abstract.
BACKGROUND: Firefighters' activities require constant adjustments of the cardiovascular system with cardiac autonomic function (CAF) playing an important role. Despite the crucial role of CAF in regulating stress response, little is known about firefighters' CAF.
OBJECTIVE: We aimed to characterize the resting on-duty and off-duty CAF of male firefighters, in association with cardiorespiratory fitness (CRF).
METHODS: We evaluated 38 firefighters in an on-duty rest condition and 26 firefighters in an off-duty laboratory-controlled condition. CAF was addressed by means of heart rate variability (HRV). We compared HRV measurements between CRF categories ($<$12METs *vs* $\geq$12METs). Wilcoxon, Mann-Whitney texts and Spearman correlation were used and General Linear Model was applied for age and BMI adjustments.
RESULTS: Firefighters' resting CAF is characterized by a predominant sympathetic modulation and a large inter-individual dispersion in all HRV indices, in both groups. We found a positive correlation between a higher CRF, the overall CAF and the higher parasympathetic activity ($p < 0{,}03$). Firefighters with CRF $\geq$12 METs showed a higher parasympathetic modulation.
CONCLUSIONS: Firefighters' resting CAF is characterized by a predominant sympathetic modulation and a large inter-individual dispersion in all HRV indices, in both groups. Our results support mandatory physical training focused in improving firefighters' CAF as a cardiopretective effect.

Keywords: Firefighting; autonomic nervous system; sympathovagal balance; physical fitness; occupational cardiovascular risk

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1. Introduction

Firefighters' work assignments may vary worldwide, but generally include fire suppression, rescues and stabilizing medical emergencies [1–3]. These job activities expose firefighters to different occupational risk factors and intense physical and psychological stressors that make firefighting a hazardous profession associated with high on-duty mortality [1, 4–7].

The unique combination of psycho-physical demands and hazardous environmental conditions lead to a very robust activation of the sympathetic nervous system coupled with a high work load that can trigger cardiovascular events in susceptible subjects [1–3]. Thus, the leading cause of on duty mortality within United States firefighters is sudden cardiac death (SCD), which account for nearly half of all duty related deaths [4]. SCD are largely associated with coronary heart disease (CHD) and cardiomegaly [8–10].

Firefighters' job-related activities require constant adjustments of the cardiovascular system in which the cardiac autonomic modulation plays an important role [2, 11, 12]. Duty-related physiological stressors are arrhythmogenic and when coupled with individual characteristics such as coronary heart disease, obesity and/or cardiomegaly may result in acute cardiovascular events [13, 14]. It is well accepted that sympathetic hyperactivity and impaired parasympathetic activity are potentially arrhythmogenic and associated with sudden cardiac death (SCD) [15, 16].

Previous studies have addressed different pathogenic mechanism to explain firefighters' myocardial infarction under fire suppression activities, such as hemoconcentration/dehydration, heat and physical stress [13, 17–19], smoke inhalation [20], increase in thrombogenicity and reduced vascular function [3, 21–24]. Cardiac autonomic function (CAF) is another potential mechanism that may affect vulnerability. It is important to consider possible associations between those mechanisms and the CAF, either affecting CAF recovery after cardiovascular strain and/or been affected by the basal cardiac autonomic status. Evaluating healthy adults, we have shown that the heart rate recovery after maximal treadmill exercise was correlated with the vagal modulation of the heart in resting orthostatic posture [25]. Also, recent studies have shown significant impairment of CAF measured by heart rate variability (HRV) associated with heat/physical stress and air/noise pollution [20, 26–28]. Despite the crucial role of CAF on physiological and pathophysiological health conditions [12, 15], especially under different cardiovascular strain situations, little is known about firefighters' resting basal CAF.

Theoretically, firefighters' resting cardiac autonomic function (CAF) could be expected to be characterized either by a sympathetic or a parasympathetic dominance. The acute, arduous and dangerous (life-threatening) conditions at accompanying heat/dehydration, psychological stressful and physical exertion that firefighters routinely encounter, and the vigilance associated with public safety work may cause acute sympathetic activation [2, 3, 29–31]. On the other hand, regular physical training, which is routinely recommended for firefighters [3, 32], results in physiological adaptations such as cardiorespiratory fitness (CRF) improvement and resting bradycardia [33, 34], which may result in a parasympathetic dominance and on a cardioprotective effect [34–36].

We aimed to characterize the resting on-duty and off-duty CAF of male firefighters by means of HRV, in association with CRF and physical activity level (PAL). We hypothesize that: 1 - firefighters have a broad spectrum of CAF but with a prevalent parasympathetic dominance at rest off-duty condition; 2 - the physically active firefighters and the firefighters with higher CRF have improved HRV and more parasympathetic dominance at rest in the off-duty condition and 3 - firefighters' CAF at rest on a readiness situation at the fire station (on-duty) is characterized by a shift toward a more sympathetic dominance as compared to a resting off-duty condition.

2. Methods

2.1. Subjects

We conducted a cross-sectional study with male firefighters recruited by convenience from the Federal District (Brasilia) Military Firefighter Brigade - Brazil (CBMDF - Portuguese acronym). The CBMDF includes all fire departments in the state of the Brazilian Federal District, where the capital Brasilia is located.

Inclusion criteria were: military career firefighters with at least five years in active firefighting duties, no medical restriction for firefighting activities, aged from 23 to 50 years, non-smokers and without known cardiometabolic diseases such as hypertension or diabetes, no other apparent clinical manifestation, and not using of any medications. We evaluated 38 firefighters in an on-duty rest condition (on-duty group) and another group of 26 firefighters in an off-duty laboratory-controlled condition as a control group (off-duty group). The control group was included in order to analyze possible effect associated with the readiness condition at the fire station *per se,* as compared to a resting basal situation out of the job environment.

The study proposal was approved by the University of Brasilia Faculty of Health Sciences Ethics Committee on Human Research and an authorization from the CBMDF was also properly obtained. All volunteers provided their informed consent and completed in person the questionnaires regarding health-related status before performing CAF evaluation. This study is part of a project focused in Brasilia Firefighter's physical fitness and occupational health: The Brasilia Firefighters Study - BFS.

2.2. Procedures

On-duty group volunteers were recruited at the fire station at the beginning of a 24 h work shift and were evaluated before any duty or physical activity. Data collection was conducted between 8 am and 11 am. All evaluations were performed in an on-duty resting condition that was characterized by resting in a readiness situation knowing that an emergency call could be received at any moment. All volunteers had previously given permission to be in a separate and quiet room at the fire station during data collection. However, all of them knew that the evaluation could be interrupted if they had to attend to any emergency call. Therefore, we intended to evaluate the firefighters' CAF in a realistic environment, obtaining CAF in an on-duty resting condition. Off-duty group volunteers were recruited at the CBMDF facilities but scheduled for evaluation at the Brasilia University Medical School Cardiovascular Laboratory on a working-day, before going to the fire station, also between 8 and 11 am. All volunteers were instructed to abstain from stimulants (tea and coffee), alcoholic beverages and physical activity for at least 12 h previous to the CAF evaluations.

All volunteers answered validated questionnaires to evaluate a) physical activity level (PAL) by the International Physical Activity Questionnaire (IPAQ - Portuguese short version) and b) CRF by a non-exercise self-report physical activity questionnaire - SRPA [37]. CRF evaluation by the SRPA questionnaire is expressed as the estimated maximum oxygen uptake ($VO_{2\,max}$) that was also divided by 3.5 to be converted into metabolic equivalents (MET) values. Afterwards, all participants' heights and weighs were measured (to the nearest 0.5 cm and 0.25 kg, respectively) barefoot and using light clothes to calculate their body mass index (BMI).

After 5 minutes in the resting supine position, CAF was addressed by means of short-term HRV, following international guidelines [38]. A continuous 5-minute R-R interval series was recorded by the Polar© heart rate monitor, that have been shown to be reliable for R-R interval acquisition [39], both in supine and orthostatic positions.

Prior to the orthostatic R-R interval recording, blood pressure was measured to verify the absence of postural hypotension.

2.3. Heart rate variability analysis

Each series of R-R intervals of the ECG was recorded according to recommendations [38]. HRV analyses was performed off-line by means of a dedicated software that has been developed and validated in the Faculty of Medicine Cardiovascular Laboratory and the Electrical Engineering Department of the University of Brasilia and according to standardized protocol which has been described in detail elsewhere [39–41].

HRV was analyzed in time and frequency domains by different indices as follows: a) time domain: the mean normal R-R interval (NRR); an overall variability index marker of the sympathetic-parasympathetic combined modulation, which is the coefficient of variation [(CV: standard deviation/mean R-R interval)*100]; and two instantaneous variability indices that are the percentage of successive R-R intervals greater than 50 ms (pNN50) and the square root of the mean squared differences of successive intervals (rMSSD), which reflect the rapid beat-to-beat parasympathetic modulation [38, 42] and b) spectral domain: low- to high-frequency absolute areas ratio (LHR: low-high ratio) that reflects the sympathovagal balance. LHR <1 is assumed to represent a dominant parasympathetic modulation and LHR >1 a relative sympathetic dominance [38, 43].

2.4. Statistical analysis

Sample data distributions were tested for normality using the Shapiro-Wilk test. The majority of the data were non-normally distributed and so we uniformly employed nonparametric statistics, expressing the results as median and extreme values. Descriptive statistics for temporal and spectral HRV indices are presented in supine and orthostatic resting positions. We performed comparisons of HRV measurements between categories of CRF (<12 METs *vs* ≥12 METs) and PAL (active *vs* insufficient active adopting the 150 minutes of moderate-vigorous physical activity per week as cut-off point). CAF responsiveness was evaluated by means of the absolute and relative variation of HRV indices in the orthostatic position in relation to the rest supine condition. We also assessed CAF by symphatovagal balance, with LHF ≥1.0 indicating a sympathetic dominance as compared to the parasympathetic one when LHR <1.0. Considering that anthropometrical/basic physiological characteristics between groups were similar ($p > 0.05$), as well as all HRV indices, the analysis of standing up effects on CAF and group comparison by CRF and PAL were thereafter performed combining both on-duty and off-duty groups ($n = 64$). Wilcoxon and Mann-Whitney texts were used when applicable. When age or BMI was different among categories of CRF we applied the General Linear Model (GLM) for adjustments. We also performed Spearman correlation analysis between the CRF and all HRV indices. The differences were considered statistically significant when a two-tailed p-value was less than 5% (<0.05). We used the IBM SPSS Statistics® 20 (IBM Corporation, USA) software package for processing and analysis of the data and Prism 5 for Mac (GraphPad Software, USA) for graphic design.

3. Results

The sample's baseline characteristics are shown in Table 1. Only 10 % of the whole sample ($n = 6$) was in the obese range for BMI and most of the cohort (73.4%) was physically active. None of the participants had known hypertension, but 8 (12.5%) had elevated values of systolic (140–149 mmHg) and/or diastolic (90–93 mmHg) blood pressure at the time of the evaluation.

Comparisons of HRV indices between on-duty and off-duty groups, both on supine and orthostatic resting postures, are shown in Table 2. None of the HRV indices were statistically different between groups (Table 2).

Table 3 shows the time- and frequency-domain indices of HRV at rest supine and orthostatic positions. LHF ratio at rest expresses sympathetic dominance with median vales equal to 1.78 in supine posture and 4.67 after standing up. Among all volunteers, in resting supine condition, only 19 firefighters (30%) showed parasympathetic dominance (LHR <1). The proportion of them between on-duty and off-duty groups was very similar (29% and 31%, respectively). Within the other 45 volunteers, 62% had a LHR >2.0. The act of standing up showed the expected autonomic response, with median HRV indices changing toward a parasympathetic withdrawal and a corresponding synergic increase in the sympathetic activation. The cardiac autonomic function responsiveness (absolute and relative difference between orthostatic and supine posture) was also

Table 1
Sample anthropometrical and basic physiological characteristics

	On-duty group ($n = 38$)	Off-duty group ($n = 26$)	p
Age	41 (35–46) years	40 (35–47) years	0.84#
BMI	26.1 (22.8–30.6) kg/m^2	26.0 (18.0–31.8) kg/m^2	0.71#
BMI - categories - *n* (%)			0.19*
Underweight	0.0 (0.0)	1 (3.3)	
Normal weight	12 (31.6)	4 (15.4)	
Overweight	24 (63.2)	17 (65.4)	
Obese	2 (5.3)	4 (15.4)	
$VO^2{}_{max}$	42.4 (31.0–47.5) mL·kg^{-1}·min^{-1}	40.0 (30.3–49.3) mL·kg^{-1}·min^{-1}	0.83#
CRF - categories- *n* (%)			0.97*
<12 METs	13 (34.2)	9 (34.6)	
≥12 METs	25 (65.8)	17 (65.4)	
PAL - *n* (%)			0.09*
Insuficiently active	13 (34.2)	4 (15.4)	
Active	25 (65.8)	22 (84.6)	
Systolic BP	119.0 (98.0–149.0) mmHg	120.0 (105.0–143.0) mmHg	0.35#
Diastolic BP	74.0 (56.0–93.0) mmHg	74.0 (60.0–100.0) mmHg	0.43#

PAL: physical activity level; Continuous variables are expressed as median (min-max) values; #Mann Whitney test p-value; *Chi-square test p-value.

Table 2
Comparison of HRV indices on resting supine and orthostatic positions between on-duty ($n = 38$) and off-duty groups ($n = 26$)

		Supine	Orthostatic
NRR (ms)	On-duty Group	914 (785–1236)	764 (638–1088)
	Off-duty Group	984 (786–1321)	803 (616–1141)
	p	0.07	0.21
CV (ms)	On-duty Group	4.5 (1.4–15.2)	5.6 (2.3–12.7)
	Off-duty Group	4.4 (2.5–10.0)	5.1 (2.3–14.8)
	p	0.96	0.45
PNN50 (%)	On-duty Group	5.7 (0.0–72.4)	3.0 (0.0–37.7)
	Off-duty Group	8.7 (0.0–50.0)	2.6 (0.0–25.3)
	p	0.49	0.65
rMSSD (ms)	On-duty Group	27.6 (7.9–119.3)	21.9 (5.8–61.3)
	Off-duty Group	33.1 (13.3–102.0)	21.7 (5.3–51.8)
	p	0.55	0.54
LHR	On-duty Group	1.74 (0.15–5.76)	4.48 (0.66–22.43)
	Off-duty Group	2.05 (0.30–6.20)	4.75 (1.20–18.20)
	p	0.49	0.98

p: *p*-value of Mann-Whitney test; values are expressed as median (extreme).

Table 3
Comparisons of median (min-max) values of HRV indices on resting supine (SUP) and orthostatic (ORT) positions ($n = 64$)

	SUP	ORT	Abs_Dif (Δ)	Rel_Dif (Δ%)	*p*
			Temporal indices		
RRi (ms)	952 (785 / 1321)	790 (616 / 1141)	–163 (–349 / –26)	–17.0 (–33.4 / –2.8)	<0.01
CV (ms)	4.4 (1.4 / 15.2)	5.5 (2.3 / 14.8)	0.6 (–7.3 / 8.1)	18.6 (–48.7 / 231.8)	<0.02
PNN50 (%)	6.6 (0.0 / 72.4)	2.8 (0.0 / 37.7)	–3.1 (–42.3 / 19.1)	–64.3 (–100 / 5971)	<0.01
rMSSD (ms)	30.2 (7.9 / 119.3)	21.8 (5.3 / 61.3)	–8.4 (–73.4 / 30.9)	–31.4 (–86.9 / 181.3)	<0.01
LHR	1.78 (0.15 / 6.2)	4.67 (0.66 / 22.4)	3.02 (–3.44 / 19.68)	228 (–71.2 / 2463)	<0.01

RRi: mean R-R interval; CV: coefficient of variation; PNN50%: percentage of successive R-R intervals greater than 50 ms; rMSSD: square root of the mean squared differences of successive intervals; TP: total power spectral area; LFn and HFn: normalized power area of the low- (LFn) and high-frequency spectral bands (HFn); LHR: low- to high-frequency absolute areas ratio; Abs_Dif: absolute difference; Rel_Dif: relative difference; *p*: *p*-value of Wilcoxon test from SUP vs ORT comparisons.

Table 4
Comparison of median (extreme) values of HRV indices at resting supine and orthostatic positions according to CRF categories ($n = 64$)

	CRF <12 METs ($n = 34$)	CRF ≥12 METs ($n = 30$)	*p*	CRF <12 METs ($n = 34$)	CRF ≥12 METs ($n = 30$)	*p*
	Supine			Orthostatic		
RRi (ms)	952 (785–1118)	951 (799–1321)	0.26	794 (616–1032)	778 (638–1141)	0.57
CV (ms)	4 (1.4–7.6)	4.6 (2.2–15.2)	0.14	4.7 (2.3–12.8)	5.7 (2.3–14.8)	0.47
PNN50 (%)	5.7 (0.0–72.4)	16.1 (0.0–57.4)	0.10	1.3 (0.0–37.7)	3.6 (0.0–28.0)	**0.07**
rMSSD (ms)	28.1 (7.9–94.8)	36.8 (12.6–119.3)	0.10	18.3 (5.3–52.0)	23.8 (5.8–61.3)	**0.03**
LHR	1.3 (0.3–6.2)	1.7 (0.2–5.8)	0.56	5.2 (0.7–22.4)	3.3 (0.8–16.4)	**0.01**

CRF: cardiorespiratory fitness; RRi: mean R-R interval; CV: coefficient of variation; PNN50%: percentage of successive R-R intervals greater than 50 ms; rMSSD: square root of the mean squared differences of successive intervals; TP: total power spectral area; LFn and HFn: normalized power area of the low- (LFn) and high-frequency spectral bands (HFn); LHR: low- to high-frequency absolute areas ratio; *p*: *p*-value after GLM adjustment for BMI.

statistically similar between on-duty and off-duty groups ($p > 0.5$).

Comparisons of HRV indices between groups are presented for CRF categories (<12 METS *vs* ≥12 METS) (Table 4). Due to statistical differences on BMI between groups of CRF, GLM was applied. There were no differences between CRF groups' age ($p = 0.07$). All indices of CAF responsiveness were similar between CRF categories ($p > 0.30$) but the absolute LHR variation after standing up. Firefighters with low CRF showed higher increase of LHR [3.8 (–0.7 / 19.7)] as compared to the more fit firefighters [2.1 (–3.4 / 12.3)] ($p < 0.01$ after adjustment for BMI).

When comparisons were made by PAL, there was no statistical difference in any of the HRV indices, after GLM adjustment for age and BMI ($p > 0{,}23$). Considering that all cases of BMI ≥30 km/m^2 ($n = 6$)

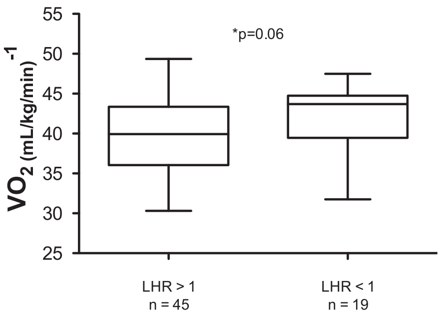

Fig. 1. Comparison of CRF between groups by sympathetic (LHR >1) or parasympathetic (LHR <1) dominance in resting supine posture. *Mann-Whintey test.

were due to elevated muscle mass component (i.e. there were no obese volunteer), no comparison between HRV indices by BMI categories was performed.

Comparison between CRF by LHR categories at supine posture is shown in Fig. 1. In the resting supine position no adjustment was need since age and BMI were similar between groups ($p = 0.12$ and 0.52, respectively).

Figure 2 illustrates different patterns of HRV within volunteers, denoting the greatly distinctive range of cardiac autonomic modulation observed in the sample.

There were significant correlations between the estimated $VO_{2\,max}$ and CV both in supine ($r_s = 0.27$; $p = 0.03$) and in orthostatic posture ($r_s = 0.31$; $p = 0.01$). Similar pattern was observed for both parasympathetic indices (PNN50% and RMSSD) in supine posture as well as after active standing up ($0.34 < r_s < 0.35$; $p < 0.006$).

4. Discussion

Our results support the hypothesis that firefighters' resting cardiac autonomic function is characterized by a predominant sympathetic modulation either in supine or in the orthostatic posture. The comparison between on-duty and off-duty groups indicates that the readiness on-duty condition per se could not explain the observed resting sympathetic dominance. We also observed a physiological CAF responsiveness to standing up and a large inter-individual dispersion in all HRV indices. Of note, we found an association between firefighters' resting HRV status and CRF, indicating higher overall HRV and parasympathetic modulation among those with better cardiorespiratory fitness. To the best of our knowledge, this is the first study to present detailed firefighters' resting HRV description, both on- and off-duty and its association with CRF.

One of the main findings was the sympathetic dominance combined with a probable low parasympathetic activity in both supine and orthostatic postures. It is important to consider that the interpretation of the firefighters' resting CAF, mainly the parasympathetic indices, is limited due to the lack of previous studies using similar HRV analysis among firefighters. However, when compared with younger, non-athlete, active adults, evaluated under laboratory-controlled conditions, our volunteers showed much lower PNN50% values (6.6% *vs* 42.9%) and higher values for LHR in the supine posture (1.78 *vs* 1.06) [40]. The higher age and lower cardiorespiratory fitness among our volunteers might explain, at least in part, these differences. In comparison with data from a group of 15 physically inactive healthy subjects (aged 26 ± 7 years; 11 men), with similar estimated cardiorespiratory fitness, the same pattern was observed at supine resting condition, i.e. our volunteers showed lower PNN50% (6.6% *vs* 28.5) and rMSSD (30.2 ms *vs* 58.1 ms) [44]. Again, when our data are compared with a previous study that included men and women from 18 to 42 years in which 25% of the sample had different clinical, anthropometrical and physical conditions that are associated with reduced HRV, firefighters' supine and orthostatic resting parasympathetic indices are still lower (PNN50%: 6.6% and 2.8% *vs* 30.1% and 4.1%; rMSSD: 30.2 ms and 21.8 ms *vs* 60.4 ms and 24.5, respectively) [39]. Considering that we found no differences between on-duty and off-duty resting HRV indices, it seams that the readiness on-duty condition prior to any duty activity did not alter the resting CAF of those experienced firefighters (>5 years of active firefighting work) toward an absolute or relative sympathetic higher activity. Therefore, it is plausible to admit that the observed sympathetic dominance and apparent vagal reduced activity might represent a CAF pattern among the majority of the firefighters, maybe associated with their frequent sympathetic activation due to routine job-related activities [2, 3, 29, 30].

Of note, more than 60% of our volunteers showed LHR >2.0 in supine resting, which is the higher value proposed as normal [38], despite the lack of HRV normal standard values from large populations studies [38, 45]. Considering that a sympathetic hyperactivity and a reduced HRV are associated with

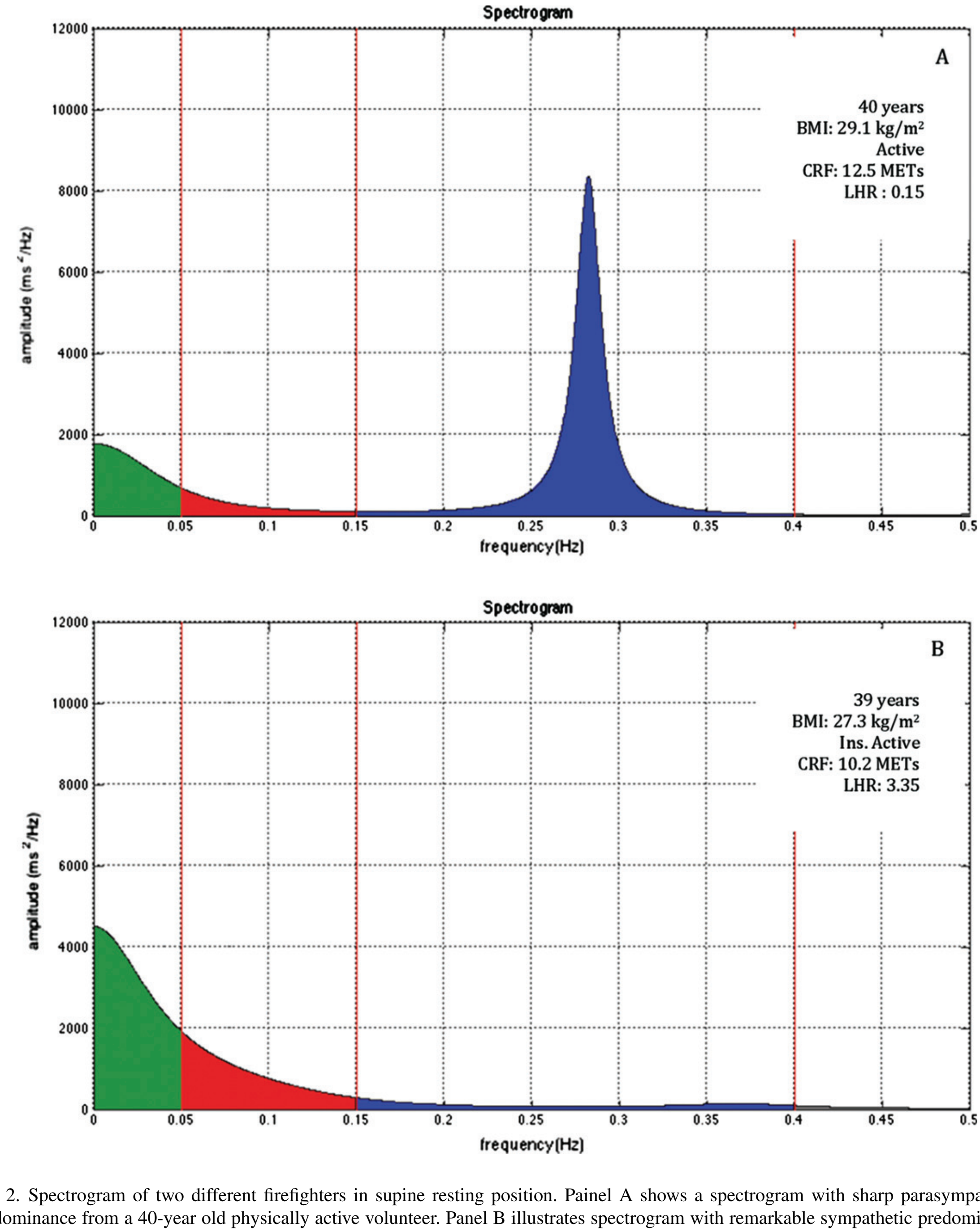

Fig. 2. Spectrogram of two different firefighters in supine resting position. Painel A shows a spectrogram with sharp parasympathetic predominance from a 40-year old physically active volunteer. Panel B illustrates spectrogram with remarkable sympathetic predominance from a 39-year old inactive volunteer. Ins. Active: insufficient active; CRF: cardiorespiratory fitness.

elevated risks of cardiovascular disease and overall mortality [1, 2, 16, 43, 46], our result may add important information to better understand the high proportion rate of on-duty cardiovascular mortality among firefighters. It is also important to recognize that our results were observed in a sample of mostly active, fit and non-obese firefighters. So, it is reasonable to expect higher proportions of sympathetic over activity and/or vagal depression among other fire departments in which high obesity and low CRF estimates of prevalence have been reported [14, 47, 48]. Also, our results should be interpreted in association with other hazardous conditions that are routinely faced by firefighters. As example, it is plausible to expect that the known negative effects of air- and noise-related pollution on cardiac autonomic regulation [28] might be amplified in those with an impaired CAF at rest. However, future studies aiming to identify the specific (separate) contributions of each different job-related stressor (e.g.: sleep breaks/deprivation, noise, low physical fitness, hazardous environment, psychological demands, etc.) on firefighters' CAF are strongly recommended.

Interestingly, the amplitude of the data and the degree of sympathetic or vagal modulation showed a large range of dispersion in the sample. Participants showed a heterogeneous cardiac autonomic modulation that may be due to individual differences in coping with the professional activity. (Tables 2–4 and Fig. 2). Despite the difficulty in defining normal ranges of variation for HRV indices, most of our median results would fit in the normal range proposed for healthy subjects but with a larger data dispersion [45]. Although the marked inter-individual dispersion, the group showed a physiological CAF responsiveness. The acute HRV adjustment to active standing up, toward an absolute or relative sympathetic dominance, was in agreement to the expected one [42, 49].

Another remarkable finding was the association between the CRF and CAF. We observed higher parasympathetic indices and lower increase of LHR after active standing up among those with CRF $\geq$12 METs as compared to those with lower CRF. In the same direction, we observed that higher CRF was correlated to higher overall cardiac autonomic modulation (i.e. higher CV) and higher vagal activity (i.e. higher PNN50% and rMSSD), both in supine and orthostatic postures. It is well accepted that higher CRF is a cardioprotective condition associated with lower cardiovascular risk and mortality [50–52]. In the general population and in firefighters, low CRF is also associated with metabolic syndrome [6] and impaired body composition [53], both conditions that could lead to increased risk for cardiovascular diseases (CVD). Also, higher CRF has been shown to have beneficial effects on CVD risk profiles regardless of BMI, while low CRF was associated with higher risk of ECG abnormalities [54, 55]. Despite our relatively small sample size, the more specific method (i.e., HRV) used in the current study allowed us to identify more specific associations between CAF and CRF. However, our cross-sectional study design prevents the identification of which comes first: high parasympathetic activity or high CRF? Some evidence supports the fact that training responsiveness is affected by previous parasympathetic activity [56, 57]. On the other hand, cardiac autonomic regulation could be positively affected by physical training, such as the bradycardia observed among endurance athletes [58, 59]. It is also plausible that both hypotheses are not mutually exclusive, but new studies with longitudinal designs are needed to clarify this intriguing question.

The study had some limitations. The relatively small sample size may have limited the chance to identify small differences between duty status, mostly in the comparison with borderline levels of statistical significance ($0.06 < p < 0.1$). Operational difficulties in evaluating a firefighter on duty during their shift work and the heterogeneity of work characteristics prevented us to include more subjects. So, we chose to focus on the homogeneity of the sample, improving the internal validity. The use of SRPA to evaluate CRF may impose imprecision estimations but this method is considered reliable [37] and have been used with similar proposal [47]. Apart from that, CRF of volunteers from all groups (on- and off-duty; higher and low CRF) was estimated with the same protocol and at the same moment of the HRV evaluation.

One strength and innovative aspect of the study protocol is the evaluation of HRV both under a laboratory-controlled condition and under a real on-duty situation. The on-duty condition was thought to be the best way to evaluate the CAF of firefighters on a real life approach, in a condition that is certainly the closest one to their real cardiac autonomic status while on readiness on-duty. In other words, we intended to evaluate firefighters' resting CAF in a basal condition and compared it to a similar condition when firefighters are at the station and available for dispatch whenever a call is received.

5. Conclusions

Our hypotheses were partially confirmed. We found a large inter-individual HRV variation but with a remarkable sympathetic dominance on a resting on- and off-duty situations in both time- and frequency-domain of HRV analysis. We also found a positive association between HRV and CRF but no association with PAL. Also, participants with better CRF tended to show a parasympathetic dominance in the resting supine position and a CAF balance toward a higher relative parasympathetic activity in the orthostatic posture. We also found no difference between on- and off-duty evaluation of CAF by means of HRV, suggesting that the readiness on-duty situation is not sufficient to explain the CAF sympathetic dominance at rest.

Our results reinforce the rationale for the inclusion of mandatory physical training focused in improving firefighters' cardiac autonomic function, health conditions and job performance capacities. Our data may also help better understanding the underlying mechanism associated with the elevated risk of on-duty sudden cardiac death among firefighters. Further studies of more firefighters of varying fitness, addressing the separate roles and interactions of different stressors and under more stressful on-duty conditions would be of value in better understanding the role of CAF in firefighters' cardiovascular risks.

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Conflict of interest

RM is a former officer of the CBMDF. No other potential conflicts of interest relevant to our study exist.

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