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Pre-competitive overload period impairs parasympathetic modulation in Athletes: A Systematic Review and Meta-analysis

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Abstract

Objective: The aim was meta-analyze the effect of different type of overloads on parasympathetic modulation to the heart, assessed by root-mean-square difference of successive normal RR intervals (RMSSD) of athletes. Methods: The analysis of the 14 studies selected (20 subgroups within studies), compared RMSSD of the same athletes before and after an overload period. Results: RMSSD of athletes were lower at pre-competition compared to baseline (SMD=-0.50 [-0.83; -0.18], p=0.002), while volume, volume and intensity and post-competition showed similar RMSSD than their respective normal load periods. Conclusion: The lower RMSSD during pre-competition overload, characterize an loss of homeostasis, and could be explained by the presence of pre-competition anxiety, stress, and higher psychological challenges in addition to the same physical stress present in the other types of overloads (i.e.: higher volume or training intensity).

Keywords: Stress, Physiological; Biomarkers, Autonomic Nervous System; Athletes; Fatigue.

1. Introduction

It is well know that athletes overtraining and loss in performance have been associated to excessive increase in internal load[1]. More recently, autonomic nervous system function has been assessed to characterize the individual internal load in the context of sports training by heart rate variability (HRV) analysis[2,3]. Different HRV indexes can be analyzed from the recording of cardiac R waves at each heartbeat by electrocardiogram or portable heart rate monitor.

Among those HRV indexes, the root-mean-square difference of successive normal RR intervals (RMSSD) represents the parasympathetic modulation and has becoming widely used in the sports context. It is due to the extraction of RMSSD from short data acquisition periods to its analysis by simpler software and to its potential as a monitoring tool to detect changes on general internal load variations, such as fatigue when correctly interpretated[4]. Despite the analysis of RMSSD is highly variable between individuals, it has low diurnal variations within subjects, its reduction along time in the same athlete could be a reliable representation of general physiological distress, and it could be able to predict clinical signals of overtraining[4–6].

A previous meta-analysis showed that vagal-related HRV indices, such as RMSSD, was not able to detect parasympathetic hyperactivity in functionally overreached athletes [7]. A limitation of this previous meta-analysis was the comparison of different individuals, since it is known that reference baseline HRV values are very different between individuals. [8,9] For instance, a young men could present a RMSSD of 24.84ms as well as 100.02ms [8] which would hinder the observation of a significant effect between a group of overreached athletes and another group of healthy athletes in this previous study [7]. It also could be due to methodological inconsistencies across studies, like different methods to analysis HRV data (i.e: daily vs. weekly, or supine vs. sitting positions, or wake vs. sleep), or the different HRV indexes chosen for analysis impairs the dopaminergic signaling[7], and the type of overload that led athletes to overreaching. Periods of high volume, intensity, and post-competition stress are potential overload stimuli to reduce RMSSD[5,6,10–16]. In addition to the same physical stress present in these types of overloads, pre-competition overload could lead to pre-competition anxiety, stress, and higher psychological challenges[17], and it may drive to different RMSSD variations. Thus, the aim of the present study was to compare the effect of different types of overloads on resting RMSSD in different periods on the same athletes by meta-analysis of previous studies.

2. Methods

The protocol review was registered on PROSPERO (International prospective register of systematic reviews) under the number CRD42020181966. Study selection and data collection were performed by two independent reviewers and the conflicts were discussed by both.

2.1 Search strategy. A highly sensitive search was performed in PubMed, Web of Science, Scopus, and Cochrane on November 4, 2020. PubMed syntax was used as a model to the equivalent syntax in other databases, combining the synonyms for "heart rate variability", "fatigue", and "Athletes". The search was not restricted by date of publication.

2.2 Study selection. Were included athletes from any modality; undergoing any type of overload stimuli; observations of the same athletes during overload and normal load period; resting HRV assessed by square RMSSD (ms, percentage or logarithm). Exclusion criteria were non-original studies athletes with disability, HRV assessed immediately after overload without an overnight resting preparation, and HRV assessed during sleep (Supplementary figure).

2.3 Data collection. The RMSSD central tendency, dispersion measurements after overload periods and normal load periods in the same group of athletes, as well as the sample size were extracted from each study. Mean, standard deviation (SD) and sample size (n) were preferred for main analysis. Standard error (SE) was converted to SD by the equation $SD = SE\times(\sqrt{n})$, if SD was not provided in the original study. The 95% confidence intervals were converted to SD considering the equation ($\sqrt{(n)} * (UL - LL)/(2 * T.INV\,(0.05; n - 1))$, where n is the sample size, UL is the upper limit, LL is the lower limit and T.INV is the function that calculates the left-tailed inverse of the Student`s T distribution. Median and interquartile range (IQR) were replaced, respectively, by mean and SD according to the equation SD = (IQR/1.35).

2.4 Statistical analysis. The meta-analysis was performed using the *Comprehensive Meta-Analysis software* (CMA) 3.3.070. Since the studies presented RMSSD in different unit measurement the meta-analysis of RMSSD standardized mean difference (SMD) between the overload and normal load period within the same athletes. Subgroup analyses were performed to compare the effects of different types of overloads (pre-competition, post-competition, volume and volume & intensity) and $p\leq0.05$ was considered significant. When inconsistency between studies (I^2) was >50%, random effects were applied, and when it was <40%, fixed effects were applied.

3. Results and Discussion

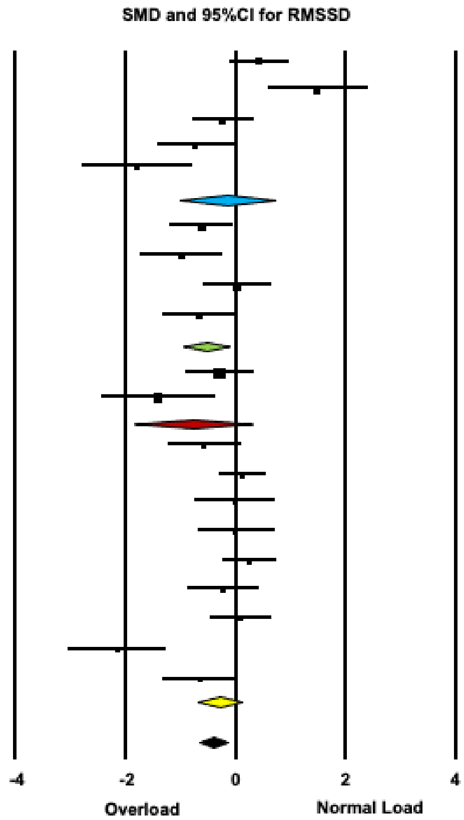
Table 1 describe the characteristics of the 14 studies included[5,6,19–22,10–16,18]. These articles led to the analysis of 20 subgroups that included athletes of endurance, collective sports, swimming, and fight; men or women; youngers, adults, and elders. The studies tested the effects of increase volume and intensity, or the effects of a pre-competition period or post-competition and two tested only volume. The intervention protocols were very diverse given the variety of sports and level of training of the athletes included, college level, elite athletes, national, international, and recreationally trained. The average duration of these interventions ranged from two to seven weeks. All athletes were healthy, except for one group of Bourdillon's study[22] that were overreached. Since the exclusion of this study did not affect our results, we opted to maintain it for final analysis.

**** please insert table 1 ****

To avoid the overlap of sample by the analysis of many results of the same individuals, some factors had priority for the main analysis. For example, when the studies assessed HRV of normal load period before and after the overload period, the preference was given for the period before overload, to avoid any vestige of overload effect at this assessment; however, it is noteworthy that some studies presented normal load values only after overload as a recovery period[11,15,20]. When the studies presented HRV assessments performed at more than one body position, the preference was given to supine position according to task force recommendation[23,24], however a few studies only presented analysis on seated position[16,21].

Figure 1. Forest Plot of overload effect on RMSSD. AF: acute fatigue; CI: confidence interval; DC: domestic competition; F: fixed model; FOR: functional overreaching; IC: international competition; LL: low limit; R: random model; SMD: standardized mean difference lower limit; UL: upper limit.

First author, year (Subgrpoup)	SMD	LL	UL	p-Value	Total	Relative Weight
Miranda-Mendoza, 2020	0.440	-0.108	0.989	0.116	14	21.50
Barrero, 2019	1.499	0.596	2.403	0.001	10	18.70
Fazackerley, 2019	-0.231	-0.782	0.320	0.412	13	21.49
Flatt, 2019 (DC)	-0.727	-1.423	-0.030	0.041	10	20.41
Flatt, 2019 (IC)	-1.783	-2.780	-0.786	0.000	10	17.89
Post-competition (R)	**-0.142**	**-1.002**	**0.718**	**0.746**	**57**	**100**
Miranda-Mendoza, 2020	-0.605	-1.175	-0.036	0.037	14	29.29
Barrero, 2019	-0.974	-1.727	-0.221	0.011	10	20.56
Flatt, 2019 (DC)	0.042	-0.578	0.662	0.893	10	26.51
Flatt, 2019 (IC)	-0.633	-1.312	0.046	0.068	10	23.63
Pre-competition (F)	**-0.504**	**-0.826**	**-0.182**	**0.002**	**44**	**100**
Flatt, 2017	-0.280	-0.912	0.352	0.385	10	57.15
Morales, 2014	-1.397	-2.438	-0.356	0.009	7	42.85
Volume (R)	**-0.759**	**-1.842**	**0.324**	**0.170**	**17**	**100**
Baumert, 2006	-0.554	-1.220	0.111	0.103	10	10.85
Bellenger, 2016	0.140	-0.280	0.560	0.514	22	13.44
Bourdillon, 2018 (AF)	-0.003	-0.744	0.737	0.993	7	10.08
Bourdillon, 2018 (FOR)	0.020	-0.673	0.713	0.954	8	10.57
Le Meur, 2013	0.261	-0.237	0.759	0.305	16	12.63
Uusitalo, 1998	-0.212	-0.873	0.449	0.529	9	10.91
Atlaoui, 2007	0.101	-0.444	0.646	0.716	13	12.13
Figueiredo, 2019	-2.138	-3.026	-1.250	0.000	16	8.69
Flatt and Hornikel, 2017	-0.640	-1.320	0.041	0.065	10	10.70
Volume and intensity (R)	**-0.272**	**-0.659**	**0.116**	**0.170**	**111**	**100**
Overall effects (R)	**-0.386**	**-0.646**	**-0.127**	**0.004**	**229**	**100**



The main finding of the present study was that only pre-competition led to significant lower RMSSD (p=0.002) in a very homogeneous analyses (I^2 = 36%), while post-competition, volume and intensity and volume did lead reduced RMSSD (p >0.05) in a considerable inconsistent analysis (Figure 1).

Despite the athletes undergo high physical overload also during pre-competition and post-competition periods, the main sources of lower pre-competition RMSSD that differs from the physical overload, might be the pre-competition stress and anxiety. Stress is a complex process that can result in emotional, cognitive and physiological changes[25]; and its pre-competition increase have been confirmed by the increase of blood cortisol levels[6] (probably because of a anticipatory response to a competitive demand). Salivary cortisol has also been associated with cognitive and somatic anxiety, in judo athletes [25]. The pre-competition anxiety has been defined as an immediate emotional state in which feelings of apprehension and tension accelerates sympathetic activity[17]. Although, pre-competition cognitive and somatic anxiety have been negative associated with post-event

RMSSD[26], here we did not find significant reduction in RMSSD post-competition, within the almost the same studies that led to reduction in RMSSD pre-competition.

Some confounding factors have been shown to influence competition anxiety in athletes such as level of training, the nature of the sport and the experimental conditions of the research. For example, Morales et al., (2013) observed that international judo level athletes experienced lower anxiety when compared to national judo athletes' level in precompetitive situations. Also, Kyrkby (2009) find that individual sports athletes presented higher anxiety levels than collective sports athletes, comparing track field against basketball athletes. At last, Blazques et al. (2009) already observed a larger increase in anxiety in competition conditions compared to usual training conditions. Nevertheless, in our analysis, the lower pre-competition RMSSD was observed among a variety of sports, including handball university college athletes, ultra-endurance runners and regional or national female cyclists[6,14,15].

Interestingly, the only study reporting decreased parasympathetic modulation during a physical overload period (volume), observed simultaneously higher markers of stress following this period, reinforcing the influence of a psychological type of stimuli on RMSSD reduction[5]. Cortisol is known as the "stress hormone" since the activation of hypothalamic-pituary-adrenal axis by stressful situations increase its levels (ref). In healthy conditions cortisol increment is followed by its reduction by an efficient feedback mechanism regulated by dopaminergic synapses; however, chronic stress, different of exercise stress stimuli, impairs the dopaminergic signaling, leading to a continuous increase in cortisol levels. It causes serious health damages, such as cognitive impairment and reduction of structural and functional brain plasticity (ref).

In the same study, the higher stress and lower RMSSD, were associated with the decrease in strength parameters which may account for performance decrements in these athletes[5]. In this way, future studies should consider autonomic modulation state and psychophysiological variables at the beginning of training or competitive season.

Additionally, studies including only women[12,14,19] led to lower RMSSD within the overall overload analysis (SMD=-0.44[-0.83;-0.05], p=0.02), while studies including only men[5,11,13,18,21] did not change RMSSD (SMD=-0.53[-1.18;0.12], p=0.11). However, there was no significant difference between sex categories (Q test p-value=0.53). The influence of the menstrual cycle on HRV is well known, and higher vagal modulation is expected due to higher progesterone levels during ovulation[27], while the opposite is expected in the luteal phase, assessed by increases in low frequency, symphatovagal balance and reduction in high frequency domain[28]. Nevertheless, the present studies did not report which phase were the athletes, adding a confounding factor that cannot be removed from our analysis.

Despite a sample overlapping from national and international competitions within Flatt`s study[21] was a limitation, the analysis without any of them led to similar results.

4. Conclusion

Pre-competition overload consistently impairs parasympathetic modulation across studies while the higher solely increase in training volume and intensity or the post-competition period did not (Figure 2). Whether the psychological parameters are in fact associated to RMSSD reduction still to be determined. The heterogeneity among some overload stimuli (post-competition, volume, and volume and intensity) suggests a need for further studies to confirm these findings.

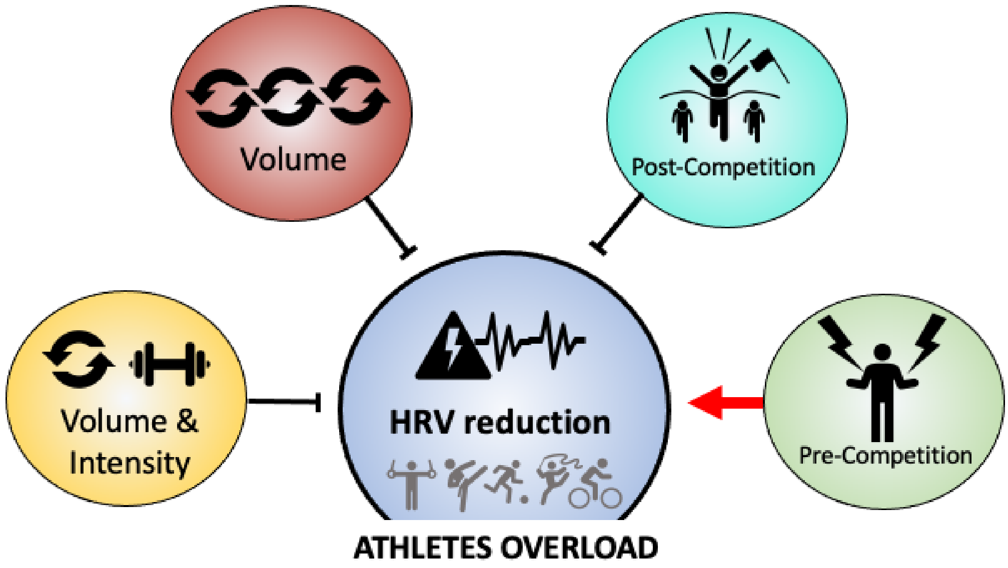


Figure 2. The subgroup meta-analysis showed that athletes have lower RMSSD at pre-competition periods while have no alteration in RMSSD at post-competition, or after increased volume, or after combined volume and intensity overload period compared to normal load periods.

5. Conflict of interest

The authors declare no conflict of interest.

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Table 1. Characteristics of the studies included.

	First author, year (Subgroup)	RMSSD Mean (SD)		n	Age Mean (SD)/training level	Sex	Overload dose	RMSSD UM	Body position	Analysis time-point
		Without overload	With overload							
Post-competition	**Miranda-Mendoza, 2020**	SU: 4 (0.31)	SU: 3.62 (0.61)	14	22.3(1.83)/ University athletes	NR	National university championship	LnRMSSD	Supine	15 min
	Barrero, 2019	SU: 93.46 (56.92)	SU: 57.2 (16.75)	10	31.7/ Regional or National level	W	C/A: High-altitude (875.5 Km)	RMSSD (ms)	Supine	7 min
	Fazackerley, 2019	SU: 4.5 (-1.082)	SU: 4.2 (-1.44)	13	36.6 (7.6)/ recreationally trained runners	M & W	Bruny island ultra-marathon.	LnRMSSD (ms)	Supine	5 min (first and final 30 s was removed)
	Flatt, 2019 (DC)	SI: 4.53 (0.4)	SI: 4.14 (0.61)	10	Not mentioned/ 2016 Olympic team	M	Domestic competition	LnRMSSD	Sitting	1 min record after 1 min stabilization
	Flatt, 2019 (IC)	SI: 4.53 (0.4)	SI: 3.6 (0.59)	10	Not mentioned/ 2016 Olympic team	M	International competition	LnRMSSD	Sitting	1 min record after 1 min stabilization
Pre-competition	**Miranda-Mendoza, 2020**	SU: 4.22 (0.4)	SU: 4 (0.31)	14	22.3(1.83)/ University athletes	NR	National university championship	LnRMSSD	Supine	15 min
	Barrero, 2019	SU: 93.43 (33.24)	SU: 59.53 (36.24)	10	31.7/ Regional or National level	W	Competition in High-altitude (875.5 Km)	RMSSD (ms)	Supine	7 min
	Flatt,2019 (DC)	SI: 4.53 (0.4)	SI: 4.55 (0.52)	10	Not mentioned/ 2016 Olympic team	M	Domestic competition	LnRMSSD	Sitting	1 min record after 1 min stabilization
	Flatt, 2019 (IC)	SI: 4.53 (0.4)	SI: 4.28 (0.39)	10	Not mentioned/ 2016 Olympic team	M	International competition	LnRMSSD	Sitting	1 min record after 1 min stabilization
Volume	**Flatt, 2017**	SU:91.33 (-4.64)	SU: 89.51 (-7.42)	10	21.6 (2)/ National Association for inter-collegiate athletics	W	+9% volume on strength session and >16% volume	LnRMSSD	Supine	1 mim after 1min stabilizantion

	Morales, 2014	SU:84.98 (-38.15)	SU: 38.83 (-19)	7	23.57(0.3)*/ national-standard judo players	M	conditioning session +3 sessions/wk (strength, endurance, and physical fitness) and + volume per session	RMSSD	Supine	10 min after 10 min adaptation
Volume and intensity	**Baumert, 2006**	SU:68 (-31.85)	SU:52 (-24.44)	10	W: 24.8 (24.7 –26.4)**; M: 26.6 (26.5 – 28.8)**/ competition experience (2 or more years)	M & W	85-90% of individual AT	RMSSD (ms)	Supine	30 min
	Bellenger, 2016	SU:10.17 (-31.22)	SU:14.61 (-32.24)	22	35.1 (7.0)/local club athletes	M	+36 min of run/day and 36% of training at 88% of HR peak	LnRMSSD (%)	Supine	3 min in each position (just the last2 minutes was used)
	Bourdillon, 2018 (AF)	SU:1.09 (-3.11)	SU:1.08 (-2.78)	7	25 (5)/ training at least 4 hours week	M & W	+≥40% Intensity	RMSSD (n.u.)	Supine	3 mim in each position(daily) \ 6 min (every third day)
	Bourdillon, 2018 (FOR)	SU: 1.06 (2.88)	SU: 1.12 (-3.27)	8	25 (5)/ training at least 4 hours week	M & W	+≥40% Intensity	RMSSD (n.u.)	Supine	3 mim in each position(daily) \ 6 min (every third day)
	Le Meur, 2013	SU: 4.22 (0.64)	SU: 4.37 (0.50)	16	30 (5)/ competing for 2 years in triathlon and training a minimum 6 times per week	M	+40% volume	LnRMSSD	Supine	8 min supine and 7 min stnding (last 4 min of each was used)
	Uusitalo, 1998	SU:79 (-33)	SU: 72 (-33)	9	23.9(3)/ not mentioned	W	+130% volume (sessions), and 70% – 90% of VO_2máx	RMSSD (ms)	Supine	5 min
	Atlaoui, 2007	SU: 70.88 (47.3)	SU: 76.32 (58.6)	13	15 (3)/ competing nationally and	M & W	+ average 47Km volume and	RMSSD (ms)	Supine	10 min after 5 min of rest in supine position

				internationally		+ 2.4 a.u. intensity			
Figueiredo, 2019	SU: 4.2 (0.14)	SU: 3.7 (0.27)	16	18.7 (0,6)/ under-19 category	M	2x10 shots of 30m; 15sec. between shots and an AR of 5 minutes/ sets	LnRMSSD (ms)	Supine	1 min after 1 min supine
Flatt and Hornikel, 2017	SI: 82.25 (6.7)	SI: 77.9 (7.6)	10	M – 21 (1.6); W – 21 (1.5)/ division – 1 national collegiate athletic association	M & W	substantial increase in IT with a volume ranging only ≥ 20%	LnRMSSD	Sitting	1 min record after 1 min stabilization

Legend: SD: AF: acute fatigue; AR: active rest; AT: aerobic threshold; A.U.: arbitrary units; DC: domestic competition; FOR: functional overreaching; standard deviation; HIT: high intensive training; IC: international competition; M: Men; NR: not reported; N.U.: normalized units; RP: recovery period; SI: sitting; ST: standing position; SU: supine position; W: women; wk: week**;** *: standard error; **: interquartile range.