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

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### **Protocol PROSPERO:**

Number: CRD42020181966

## 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<sup>1</sup>. 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<sup>2,3</sup>. 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 interpreted<sup>4</sup>. 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<sup>4-6</sup>.

A previous meta-analysis showed that vagal-related HRV indices, such as RMSSD, was not able to detect parasympathetic hyperactivity in functionally overreached athletes<sup>7</sup>. 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<sup>8,9</sup>. For instance, a young men could present a RMSSD of 24.84ms as well as 100.02ms<sup>8</sup> 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<sup>7</sup>. 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<sup>7</sup>, 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<sup>5,6,10-16</sup>. 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<sup>17</sup>, 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  $p \leq 0.05$  was considered significant. When inconsistency between studies ( $I^2$ ) was  $>50\%$ , random effects were applied, and when it was  $<40\%$ , fixed effects were applied.

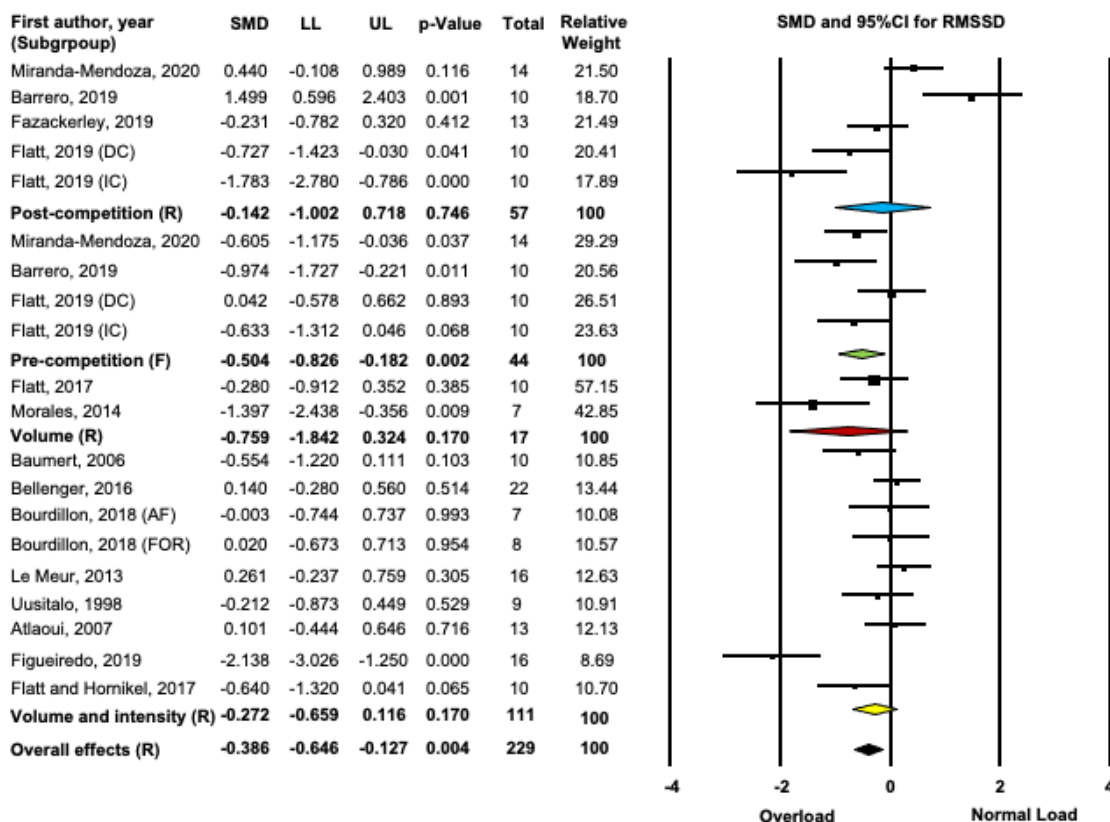
## 3. Results and Discussion

Table 1 describe the characteristics of the 14 studies included<sup>5,6,19–22,10–16,18</sup>. 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<sup>22</sup> 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<sup>11,15,20</sup>. 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<sup>23,24</sup>, however a few studies only presented analysis on seated position<sup>16,21</sup>.

**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.



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<sup>25</sup>; and its pre-competition increase have been confirmed by the increase of blood cortisol levels<sup>6</sup> (probably because of a anticipatory response to a competitive demand). Salivary cortisol has also been associated with cognitive and somatic anxiety, in judo athletes<sup>25</sup>. The pre-competition anxiety has been defined as an immediate emotional state in which feelings of apprehension and tension accelerates sympathetic activity<sup>17</sup>. Although, pre-competition cognitive and somatic anxiety have been negative associated with post-event

RMSSD<sup>26</sup>, 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<sup>6,14,15</sup>.

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<sup>5</sup>. Cortisol is known as the “stress hormone” since the activation of hypothalamic-pituitary-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).

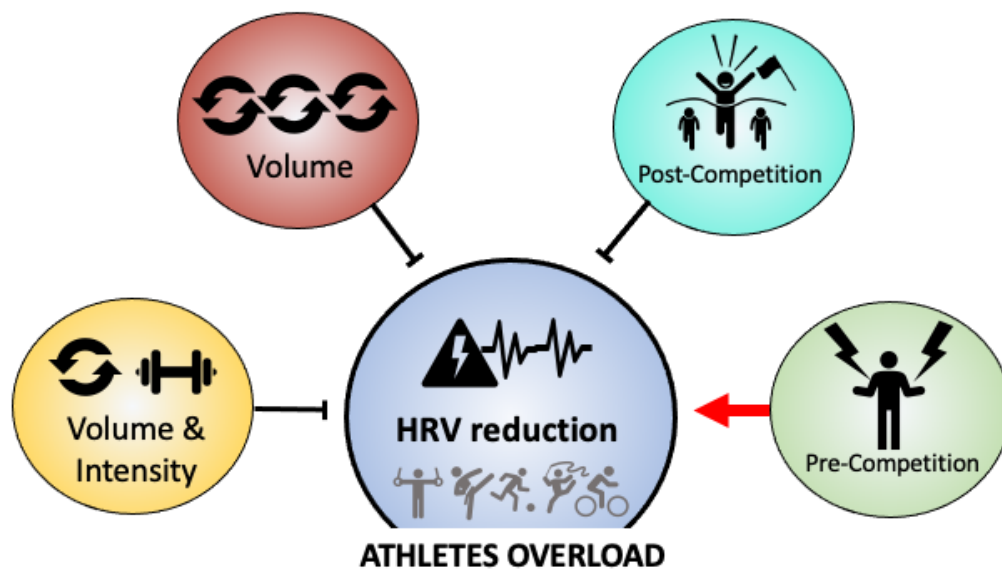
In the same study, the higher stress and lower RMSSD, were associated with the decrease in strength parameters which may account for performance decrements in these athletes<sup>5</sup>. In this way, future studies should consider autonomic modulation state and psychophysiological variables at the beginning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

Additionally, studies including only women<sup>12,14,19</sup> led to lower RMSSD within the overall overload analysis (SMD=-0.44[-0.83;-0.05], p=0.02), while studies including only men<sup>5,11,13,18,21</sup> 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<sup>27</sup>, while the opposite is expected in the luteal phase, assessed by increases in low frequency, symphatovagal balance and reduction in high frequency domain<sup>28</sup>. 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<sup>21</sup> 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.

## 6. REFERENCES

1. Budgett R. Fatigue and underperformance in athletes: The overtraining syndrome. *Br J Sports Med.* 1998;32(2):107-110. doi:10.1136/bjism.32.2.107
2. Nakamura FY, Flatt AA, Pereira LA, Ramirez-Campillo R, Loturco I, Esco MR. Ultra-short-term heart rate variability is sensitive to training effects in team sports players. *J Sport Sci Med.* 2015;14(3):602-605.
3. Djaoui L, Haddad M, Chamari K, Dellal A. Monitoring training load and fatigue in soccer players with physiological markers. *Physiol Behav.* 2017;181(September):86-94. doi:10.1016/j.physbeh.2017.09.004
4. Buchheit M. Monitoring training status with HR measures: Do all roads lead to Rome? *Front Physiol.* 2014;5 FEB(February):1-19. doi:10.3389/fphys.2014.00073
5. Morales J, Alamo JM, García-Massó X, et al. Use of heart rate variability in monitoring stress and recovery in judo athletes. *J strength Cond Res.* 2014;28(7):1896-1905. doi:10.1519/JSC.0000000000000328
6. Miranda-Mendoza J, Reynoso-Sanchez LF, Hoyos-Flores JR, et al. Stress Score and LnRMSSD as Internal Load Parameters During Competition. *Rev Int Med Y CIENCIAS LA Act Fis Y DEL Deport.* 2020;20(77):21-35. doi:10.15366/rimcafd2020.77.002
7. Manresa-Rocamora A, Flatt AA, Casanova-Lizón A, et al. Heart rate-based indices to detect parasympathetic hyperactivity in functionally overreached athletes. A meta-analysis. *Scand J Med Sci Sport.* 2021;31(6):1164-1182. doi:10.1111/sms.13932
8. Sammito S, Böckelmann I. Reference values for time- and frequency-domain heart rate variability measures. *Hear Rhythm.* 2016;13(6):1309-1316. doi:10.1016/j.hrthm.2016.02.006

9. O'Neal WT, Chen LY, Nazarian S, Soliman EZ. Reference Ranges for Short-Term Heart Rate Variability Measures in Individuals Free of Cardiovascular Disease: The Multi-Ethnic Study of Atherosclerosis (MESA). *Physiol Behav.* 2017;176(3):139-148. doi:10.1016/j.jelectrocard.2016.06.008.Reference
10. Baumert M, Brechtel L, Lock J, et al. Heart rate variability, blood pressure variability, and baroreflex sensitivity in overtrained athletes. *Clin J Sport Med.* 2006;16(5):412-417. doi:10.1097/01.jsm.0000244610.34594.07
11. Bellenger CR, Karavirta L, Thomson RL, Robertson EY, Davison K, Buckley JD. Contextualizing Parasympathetic Hyperactivity in Functionally Overreached Athletes With Perceptions of Training Tolerance. *Int J Sports Physiol Perform.* 2016;11(7):685-692. doi:10.1123/ijssp.2015-0495
12. Flatt AA, Esco MR, Nakamura FY, Plews DJ. Interpreting daily heart rate variability changes in collegiate female soccer players. *J Sports Med Phys Fitness.* 2017;57(6):907-915. doi:10.23736/S0022-4707.16.06322-2
13. Figueiredo DH, Figueiredo DH, Moreira A, Gonçalves HR, Stanganelli LCR. Effect of Overload and Tapering on Individual Heart Rate Variability, Stress Tolerance, and Intermittent Running Performance in Soccer Players During a Preseason. *J strength Cond Res.* 2019;33(5):1222-1231. doi:10.1519/JSC.0000000000003127
14. Barrero A, Schnell F, Carrault G, et al. Daily fatigue-recovery balance monitoring with heart rate variability in well-trained female cyclists on the Tour de France circuit. *PLoS One.* 2019;14(3):e0213472. doi:10.1371/journal.pone.0213472
15. Fazackerley LA, Fell JW, Kitic CM. The effect of an ultra-endurance running race on heart rate variability. *Eur J Appl Physiol.* 2019;119(9):2001-2009. doi:10.1007/s00421-019-04187-6
16. Flatt AA, Hornikel B, Esco MR. Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. *J Sci Med Sport.* 2017;20(6):606-610. doi:10.1016/j.jsams.2016.10.017
17. Martens R, Vealey RS, Burton D. *Competitive Anxiety in Sports.* HUMAN KINETICS; 1990. [https://books.google.com.br/books?hl=pt-BR&lr=&id=MNIldMfnlb0cC&oi=fnd&pg=PR7&dq=Competitive+Anxiety+in+Sports.+HUMAN+KINETICS%3B+1990&ots=d33j23HA7E&sig=oUBIVXEizI9sm9ld6a6AOxvU2v4&redir\\_esc=y#v=onepage&q=Competitive Anxiety in Sports. HUMAN KINETICS%3B 1](https://books.google.com.br/books?hl=pt-BR&lr=&id=MNIldMfnlb0cC&oi=fnd&pg=PR7&dq=Competitive+Anxiety+in+Sports.+HUMAN+KINETICS%3B+1990&ots=d33j23HA7E&sig=oUBIVXEizI9sm9ld6a6AOxvU2v4&redir_esc=y#v=onepage&q=Competitive+Anxiety+in+Sports.+HUMAN+KINETICS%3B+1)
18. Le Meur Y, Pichon A, Schaal K, et al. Evidence of parasympathetic hyperactivity in functionally overreached athletes. *Med Sci Sports Exerc.* 2013;45(11):2061-2071. doi:10.1249/MSS.0b013e3182980125
19. Uusitalo AL, Uusitalo AJ, Rusko HK. Endurance training, overtraining and baroreflex sensitivity in female athletes. *Clin Physiol.* 1998;18(6):510-520. doi:10.1046/j.1365-2281.1998.00121.x
20. Atlaoui D, Pichot V, Lacoste L, Barale F, Lacour J-R, Chatard J-C. Heart rate variability, training variation and performance in elite swimmers. *Int J Sports Med.* 2007;28(5):394-400. doi:10.1055/s-2006-924490
21. Flatt AA, Howells D, Williams S. Effects of consecutive domestic and international tournaments on heart rate variability in an elite rugby sevens team. *J Sci Med Sport.* 2019;22(5):616-621. doi:10.1016/j.jsams.2018.11.022
22. Bourdillon N, Yazdani S, Nilchian M, Mariano A, Vesin J-M, Millet GP. Overload blunts baroreflex only in overreached athletes. *J Sci Med Sport.* 2018;21(9):941-949. doi:10.1016/j.jsams.2018.01.008
23. Task Force. Guidelines Heart rate variability. *Eur Heart J.* 1996;17(3):354-381. <https://www.escardio.org/static-file/Escardio/Guidelines/Scientific-Statements/guidelines-Heart-Rate-Variability-FT-1996.pdf>
24. Malik M, Camm AJ, Bigger JT, et al. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. *Eur Heart J.* 1996;17(3):354-381.



- doi:10.1093/oxfordjournals.eurheartj.a014868
25. Filaire E, M. S, C. F, F. M, G. L. Psychophysiological stress in judo athletes during competitions. *J Sports Med Phys Fitness*. 2001;41(2):263-268.  
<http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed5&NEWS=N&AN=2001326311>
  26. Fortes LS, da Costa BDV, Paes PP, do Nascimento Júnior JRA, Fiorese L, Ferreira MEC. Influence of competitive-anxiety on heart rate variability in swimmers. *J Sport Sci Med*. 2017;16(4):498-504. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5721179/>
  27. Weissman A, Lowenstein L, Tal J, Ohel G, Calderon I, Lightman A. Modulation of heart rate variability by estrogen in young women undergoing induction of ovulation. *Eur J Appl Physiol*. 2009;105(3):381-386. doi:10.1007/s00421-008-0914-4
  28. Bai X, Li J, Zhou L, Li X. Influence of the menstrual cycle on nonlinear properties of heart rate variability in young women. *Am J Physiol - Hear Circ Physiol*. 2009;297(2). doi:10.1152/ajpheart.01283.2008

**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	<b>Miranda-Mendoza, 2020</b>	SU: 4 (0.31)	SU: 3.62 (0.61)	14	22.3(1.83)/ University athletes	N	National university championship	LnRMSSD	Supine	15 min
	<b>Barrero, 2019</b>	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
	<b>Fazackerley, 2019</b>	SU: 4.5 (-1.082)	SU: 4.2 (-1.44)	13	36.6 (7.6)/ recreational/y trained runners	M & W	Bruny island ultra-marathon.	LnRMSSD (ms)	Supine	5 min (first and final 30s was removed)
	<b>Flatt, 2019 (DC)</b>	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
	<b>Flatt, 2019 (IC)</b>	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	<b>Miranda-Mendoza, 2020</b>	SU: 4.22 (0.4)	SU: 4 (0.31)	14	22.3(1.83)/ University athletes	N	National university championship	LnRMSSD	Supine	15 min
	<b>Barrero, 2019</b>	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
	<b>Flatt,2019 (DC)</b>	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
	<b>Flatt, 2019 (IC)</b>	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	<b>Flatt, 2017</b>	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 min after 1min stabilization

	<b>Morales, 2014</b>	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	<b>Baumert, 2006</b>	SU:68 (-31.85)	SU:52 (-24.44)	1 0	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
	<b>Bellenger, 2016</b>	SU:10.17 (-31.22)	SU:14.61 (-32.24)	2 2	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 last 2 minutes was used)
	<b>Bourdillon, 2018 (AF)</b>	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 min in each position(daily) \ 6 min (every third day)
	<b>Bourdillon, 2018 (FOR)</b>	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 min in each position(daily) \ 6 min (every third day)
	<b>Le Meur, 2013</b>	SU:4.22 (0.64)	SU:4.37 (0.50)	1 6	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 standing (last 4 min of each was used)
	<b>Uusitalo, 1998</b>	SU:79 (-33)	SU:72 (-33)	9	23.9(3)/ not mentioned	W	+130% volume (sessions), and 70% – 90% of VO <sub>2</sub> máx	RMSSD (ms)	Supine	5 min
	<b>Atlaoui, 2007</b>	SU:70.88 (47.3)	SU:76.32 (58.6)	1 3	15 (3)/ competing nationally and	M & W	+ average 47Km volume and	RMSSD (ms)	Supine	10 min after 5 min of rest in supine position

<b>Figueiredo, 2019</b>	SU: 4.2 (0.14)	SU: 3.7 (0.27)	1 6	internationally 18.7 (0,6)/ under-19 category	M	+ 2.4 a.u. intensity 2x10 shots of 30m; 15sec. between shots and an AR of 5 minutes/ sets	LnRMSS D (ms)	Supine	1 min after 1 min supine
<b>Flatt and Hornikel, 2017</b>	SI: 82.25 (6.7)	SI: 77.9 (7.6)	1 0	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 $\geq 20\%$	LnRMSS D	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.

