Influence of a 100-mile Ultramarathon on Heart Rate and Heart Rate Variability

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Research Article

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Abstract

BACKGROUND: The aim of this study was to investigate the impact of an ultra-marathon (UM) with a distance of 100 miles on heart rate (HR) and heart rate variability (HRV). METHODS: 28 runners (25 males and 3 females) underwent 24-hour Holter ECG monitoring one week before the UM (U1), immediately after (U2) the UM and after a week of recovery (U3). The influence of age, body mass index (BMI), HR and HRV on the run time as well as recovery were investigated. RESULTS: A rise in the baseline heart rate (18.98%) immediately after the run accompanied by a significant drop in the standard deviation of all normal RR intervals (SDNN) (7.12%) one week after. Except for the age of the runners, BMI, HR and HRV showed no influence on the competition time. Full return of HRV to the athletes´ individual baseline did not occur within one week. There were no significant differences between finishers and non-finishers in analysed parameters.

CONCLUSION: The present results show that a 100-mile run leads to an increase in sympathetic activity and thus to an increase in heart rate and a decrease in HRV. In addition, HRV might be a suitable parameter to evaluate full recovery after a 100-mile run.

Background:

In endurance sports the heart rate variability (HRV) has been given a high priority in recent years to optimize timing and intensity of training for optimal preparation for competition highlights (1,2,3).

Studies by Scott et al. (4) and Nagashima et al. (5) substantiated the influence of extreme endurance sports on the cardiovascular system. Scott et all. (4) were able to show a reduced left ventricular function and an increase of biomarkers (especially of NT- pro- BNP) after running extreme distances. In another study of ultramarathon runners from Japan, Nagashima et all. (5) showed an enlargement of all ventricles and the aortic root diameter. Further studies showed that regular endurance training leads to an increase in HRV (2, 6). In addition, an increase in HRV showed improved endurance performance (7). However, fatigue and exhaustion also influence HRV and lead to its reduction (8). This explains the frequent use of HRV as a non-invasive parameter that helps to determine the current training status and the current regeneration phase of athletes. This specific examination is necessary for achieving high athletic performance and helps to assess and control the training load and the autonomic effects of physical effort on the athletes (9,10).

Nevertheless the interpretation of HR and HRV in the context of endurance sports is still a controversial topic. While, Pichot et al. demonstrated an increase in HRV indices after a one-week period of over- training in non-athletes (11), another study of two elite triathletes by Plews et al. (12) reported even a decrease both in HR and HRV following exertion to full physical capacity. The last finding being thought to be due to a maximum vagal activity, with the results of a limited modulation capacity of the HRV parameters (13) due to already saturated acetylcholine receptors. In addition, Schmitt et al. showed withthe French national skiing team that in periods of physical fatigue, a decrease in the HRV parameters is recorded (8).

Until now there was only one study that investigated this impact particularly in doing an ultra- marathon of about 64km (14). Fazackerley et al. determined an increase in heart rate accompanied by decreased in HRV parameters one day after completing a 64km run. In this study indices of HRV had returned to baseline within two days after the run.

Therefore, we hypothesize that, after completing an UM of about 160,934km, the sympathetic proportion of the autonomic nervous system increases and HRV decreases similarly. Furthermore, a return of the heart rate and HRV to the baseline might be suspected after a one-week recovery based on the study by Fazackerley.

Consequently, the aim of this study was to evaluate the impact of a 100 miles UM on the HR and HRV as parameters of the autonomic effects of physical exertion and the recovery after an exertion to full physical capacity.

Methods:

1. Patients and Measurement:

Several athletes registered for the 100-mile ultra-marathon “Berliner Mauerweglauf”. The volunteer participants were recruited and examined (age, height, weight). Overall, 28 athletes (25 males and 3 females) of different age groups with a mean age of 49 years (from 26 to 67) and a mean BMI of 23.97 (from 20.07 to 30.04) were included into the study. All of them received a 24-hour Holter ECG seven days before the start of the run (U1), immediately after the run (U2) and after seven days of recovery (U3).

The "Berliner Mauerweglauf" is an ultramarathon with a distance of 100 miles, which has been held annually in August since 2011 and was founded and organized by the "Laufgruppe Mauerweg Berlin e.V.". It is a mainly flat, mostly asphalted route, which runs partly through urban areas, but also through forests. Due to its length and the time limit of 30 hours, the route is not closed to public transport.

The investigation conforms to the principles outlined in the Declaration of Helsinki (15). The study protocol has been approved by the ethics committee Charité-Universitätsmedizin (EA2/133/17) and athelete´s were included after medical assessment by an experienced sports physician and informed consent was obtained from every participant.

Holter ECGs were analysed using the "Custo Diagnostik v 4.6” (custo med GmbH, Ottobrun, Germany) software. The heart rate (beats per minute, bpm), the HRV values with SDNN (the standard deviation of all normal RR intervals), pNN50 (the percentage of pairs of RR intervals that are more than 50ms apart), RMSSD (Root Mean Square of Successive Differences) and the Vegetative Quotient (VQ, as Measure of the relationship of slower, sympathetic variability to fast, vagally induced variability) were analysed..

2. Statistics:

Data analysis was performed using SPSS statistics V.25 software. Mann-Whitney test was used for continuous variables. Chi square testing or Fisher´s exact testing was used for dichotomous variables as appropriate. To characterize the influence between continuous variables bivariate correlation was used and Pearson correlation coefficient (r) is reported. For this study, α was set at 0.05; thus P-values

< 0.05 (two-sided) were required for statistical significance.

Using multiple linear regression, the influence of age, BMI, HR in U1 and the vegetative parameters on the achieved running time, as well as the influence of these parameters on the recovery value, which is characterized by the SDNN in U3, was calculated.

Results:

Participant's characteristics:

Participant´s characteristics are shown in table 1.

23 of these athletes completed the entire 100-mile run (finisher with an average runtime of 23:03:37h). The remaining 5 athletes gave up and did not finish the UM (non-finisher). It has to be mentioned that the data sets of the U1 are missing for one finisher, in U2 there are five incomplete data sets and in U3 there are three incomplete data sets. All missing data were due to technical issues with the recording of the Holter ECG.

Investigation results:

Influences on finishing time:

First of all, older athletes had much longer finish times than younger competitors (p= .046). Yet, no significant correlation could be found between the body mass index (p= .261) or baseline resting heart rate (p= .321) and the time needed to complete the marathon. There was also no correlation between the parameters of the autonomic nervous system and the achieved running time in our study (table 2).

Comparison of finishers to non-finishers:

A comparison of the finishers (F) to the non-finishers (NF) showed no significant differences in age (F 50.82 years, NF 42.80 years, p= .115) and BMI (F 23.87 kg/m², NF 24.39 kg/ m², p= .571). Nevertheless, comparing the vegetative diagnostics in U1, higher SDNN averages are seen for non-finishers (F 70.19, NF 100.22) at lower RMSSD averages (F 75.96, NF 60.90). In the U3, higher SDNN averages (F 64.40, NF 76.80) are also evident for non-finishers, but also higher RMSSD averages (F 49.43, NF 77.76) (table 3).

Parameters of autonomic regulation:

It could be seen that the higher the measured heart rate of the athletes (especially in U2), the lower the SDNN value. But the difference between the values of HF in U1 and U2 did not affect the magnitude of the change in the SDNN value (U1: p=.235; U2: p=.363).

But comparing the heart rates, as well as the HRV of the double runners of both years, did not reveal any relevant differences in all three examinations, the run times were also nearly identical (HR p= .126, SDNN p= .763, RMSSD= .791, pNN50= .5, Veg. ration p= .558) (table 4).

Parameters of post- exertional recovery:

Comparing the values seven days before the ultramarathon (U1) with the values seven days after (U3), no significant difference between the results of the heart rates could be determined (HF p= .271). However, based on HRV (SDNN, RMSSD, and pNN50) it is noticeable that the average the values after seven days of recovery are still considerably below the baseline values (graph 1- 4). Noticeably, these differences did not reach the level of significance, except for the values of the SDNN (SDNN= .033, RMSSD= .394, pNN50= .087) (table 5).

The initial values of the vegetative parameters as part of the regression calculation have a significant influence (SDNN U1 B=.602, p=.000, RMSSD U1 B=.214, p=.000, pNN50 U1 B=.608, p=.028) on the recovery value, which is characterized by the SDNN in U3. Neither the age (p=.283) nor the BMI, (p=.485) nor the achieved runtime (p=.265) influence the recovery value.

Discussion:

The aim of our study was to evaluate the influence of running an ultramarathon over a distance of 100 miles on the heart rate and the HRV, as well as the potential use of these parameters to predict the status of recovery to full physical capacity following this exertion.

In consistency with published data (8, 11, 12, 13, 14), the presented study found an increase in the heart rate during the first hours after the UM (U2). This is commonly accepted to be due to a shift of the autonomic nervous system in favour of sympathetic activity (16, 17). This sympathetic dominance leads to a decline of the SDNN value, which describes the cooperation between the sympathetic and parasympathetic nerves (18, 19) and is consistent with our data. In fact, an increase in vagal heart control, as seen in our measurements of RMSSD between U1 and U2, often reflects an improvement in fitness, while the athlete's fatigue and impaired performance is often associated with reduced vagal HRV, which is evident when comparing RMSSD values between U1 and U3 (Table 1)(20, 21).

Yet, the main finding of the current study is shown in the comparison of the parameters of autonomic nervous system seven days before the run (U1) with the measurements seven days after the run (U3). While the baseline heart rate at U1 did not show significant differences to the measurements at U3, it can be seen that there is still no full return to baseline of the HRV at (U3), shown by lower average values for the SDNN, RMSSD and pNN50 (graphs 1-4). First of all, these results seem to indicate that even 7 days after the 100 miles, the athletes have not yet fully recovered from the effort in terms of vegetative parameters. A similar result was shown by Velenzano, et al. (2016) who examined an ultra endurance swim athlete covering a distance of 78.1km, whose HRV was still lower after 16 hours of recovery compared to his initial HRV (22). The study by Chambers et all. (2010) showed that the heart rate response to renewed steady- state exercises after a 90 km marathon takes almost a month to return to the same initial values. (23). Also Nicolas et all. (2011) were able to show that stress and recovery values after a 24-hour race (100km) take 2 weeks to return to baseline level (24). Our data imply, that in terms of recovery after a 100 miles run, HRV seems to be more accurate in the prediction of recovery, than the absolute heart rate. Although these findings stand in contrast to the findings of Fazackerley et al., whose runners achieved a return of HRV to baseline within two days after 64km run, this difference might be explained by the shorter distance covered or superior physical fitness of the athlete`s reported in the Fazackerley study.

Although the HR and HRV seem to be useful to evaluate recovery after such an extreme exertion, none of the physiological parameters, neither the baseline HR, nor the baseline HRV seem to predict the finishing time.

When analysing the data to factors influencing the finishing times, the presented data showed that only the age of the runners had an effect.

Because of the low number of participants in this study, the following might only be speculated. The low pre- race RMSSD mean of non-finishers, which is also referred to as the body's rate of recovery (6, 25) might be interpreted as a better ability of the finishers to regenerate in advance. The fact that RMSSD in U3 was higher in the non- finishers than in the finishers is probably justified with the considerably lower running distance covered by the non- finishers (table 3).

The presented data imply that none of the parameters predicting post- exertional recovery can be used to predict finishing times or the ability to finish an ultramarathon as such. It can only be speculated that there are not only physiological factors influencing the finishing of an ultra-marathon, but also psychological and environmental factors that mainly influence the coping with such a large distance.

Study Limitations:

Limitations of this study include the low number of subjects, which could limit the ability to detect statistical significance, and the lack of further post-run control to establish an exact time to return to baseline.

A prospective study with more patients, multiple follow-ups, and the capture of multiple predictors such as mental health, exercise status, or weather conditions, could help to quantify the differences between finishers and non-finishers, as well as the impact of other factors on the run time.

There are no potential sources of conflict of interest in our study.

Conclusions:

The presented results imply an increase in sympathetic activity reflected by an increase in heart rate and decrease of HRV during the first 24h post- race, in athletes after a 100-mile run. Furthermore, data suggest a possible suitability of the HRV for evaluation of full recovery after a 100-mile run.

Abbreviations

UM: ultra- marathon

HR: heart rate

HRV: heart rate variability

BMI: body mass index

ECG: Electrocardiography

U1: Investigation seven days before the run

U2: Investigation immediately after the run

U3: Investigation seven days after the run

bpm: beats per minute

SDNN: the standard deviation of all normal RR intervals

pNN50: the percentage of pairs of RR intervals that are more than 50ms apart RMSSD: Root Mean Square of Successive Differences

VQ: Vegetative Quotient

r: Pearson correlation coefficient

F: Finisher

NF: Non- Finisher

NT- pro- BNP: N terminale pro brain natriuretic peptide

e.V.: eingetragener Verein/ incorporated association

Declarations

Ethics approval and consent to participate:

The investigation conforms to the principles outlined in the Declaration of Helsinki (7). The study protocol has been approved by the ethic committee Charité-Universitätsmedizin (EA2/133/17) and athlete´s were included after medical assessment by an experienced sports physician and informed consent was obtained from every participant.

Consent for Publication:

Not applicable

Availability of data and material:

The data collected and analysed in the present study are not publicly available due to ethical restrictions but are available from the corresponding author upon request.

Competing interests:

The authors declare that they have no competing interests.

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Authors' contributions:

SS, CP and JW designed the research question. PSH and TT conducted the testings and data collections. SS and CP analysed the data. SS and CP wrote the main parts of the manuscript. All the authors contributed to critical review of draft manuscripts and approved the final manuscript.

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Tables

	N	Minimum	Maximum	Median	Standard deviation
Age (in years)	28	26	67	49.14	9.93
BMI (in kg/m²)	28	20.07	30. 04	23.48	2.12
Run- time (in h:min:sec)	23	15:25:14	28:57:45	23:30:12	03:57:03
HR in U1	28	50 bpm	109 bpm	71bpm	11.76 bpm
SDNN U1	26	35.88 ms	208.74 ms	60.495 ms	38.38 ms
RMSSD U1	27	26.8 ms	353.7 ms	40.9ms	76.65 ms
pNN50 U1	27	1.9 %	49.7 %	7.1 %	14.30 %
VQ U1	26	0.23	1.78	0.855	0.41
HR in U2 (in bpm)	24	62 bpm	127 bpm	80 bpm	15.95 bpm
SDNN U2	21	23.89 ms	416.40 ms	45.35 ms	96.68 ms
RMSSD U2	22	24.8 ms	423.5 ms	96.05ms	107.93 ms
pNN50 U2 (in %)	22	0.7 %	55.6 %	11.7 %	17.71 %
VQ U2	21	-1.65	1.78	0.66	0.81
HR in U3 (in bpm)	27	55 bpm	96 bpm	69 bpm	8.47 bpm
SDNN U3	25	34.88 ms	147.8 ms	59.79ms	23.64 ms
RMSSD U3	26	25.1 ms	177.4 ms	45.9ms	31.97 ms
pNN50 U3	26	2.6 %	25.9 %	9.4%	7.26 %
VQ U3	25	0.38	1.38	0.85	0.34

Table 1 participant´s characteristics

			Running time in h	HR - U1	SDNN U1	RMSSD U1	pNN50 U1	VQ U1
Spearman-Rho	Running time in h	correlation coefficient	1	0.258	-0.044	-0.147	-0.102	-0.12
		Sig. (2-sided)	.	0.234	0.846	0.514	0.65	0.594
	HR - U1	correlation coefficient	0.258	1	-0.419	-0.293	-.463*	0.376
		Sig. (2-sided)	0.234	.	0.052	0.185	0.03	0.085
	SDNN U1	correlation coefficient	-0.044	-0.419	1	.597**	.823**	-0.137
		Sig. (2-sided)	0.846	0.052	.	0.003	0	0.544
	RMSSD U1	correlation coefficient	-0.147	-0.293	.597**	1	.727**	-.575**
		Sig. (2-sided)	0.514	0.185	0.003	.	0	0.005
	pNN50 U1	correlation coefficient	-0.102	-.463*	.823**	.727**	1	-.441*
		Sig. (2-sided)	0.65	0.03	0	0	.	0.04

Table 2 - Correlation

Comparison between Finisher and Non- Finisher in U3					
	N	**average**	**standard deviation**	**standard deviation of the average**	**Sig. (2-sided)**
Finisher	22	70.09	8.922	1.90	
HR – U3					
Non- Finisher	5	66.8	6.14	2.75	
					.352
Finisher	20	64.40	23.86	5.34	
SDNN U3					
Non- Finisher	5	76.8	22.23	9.94	
					.311
Finisher	21	49.43	20.21	4.41	
RMSSD U3					
Non- Finisher	5	77.76	59.46	26.59	
					.350
Finisher	21	9.71	6.28	1.37	
pNN50 U3					
Non- Finisher	5	15.38	10.01	4.48	
					.283
Finisher	20	0.83	0.32	0.07	
VQ U3					
Non- Finisher	5	1.04	0.39	0.17	
					.308

Table 3 Comparison between Finisher and Non- Finisher in U3

Figures

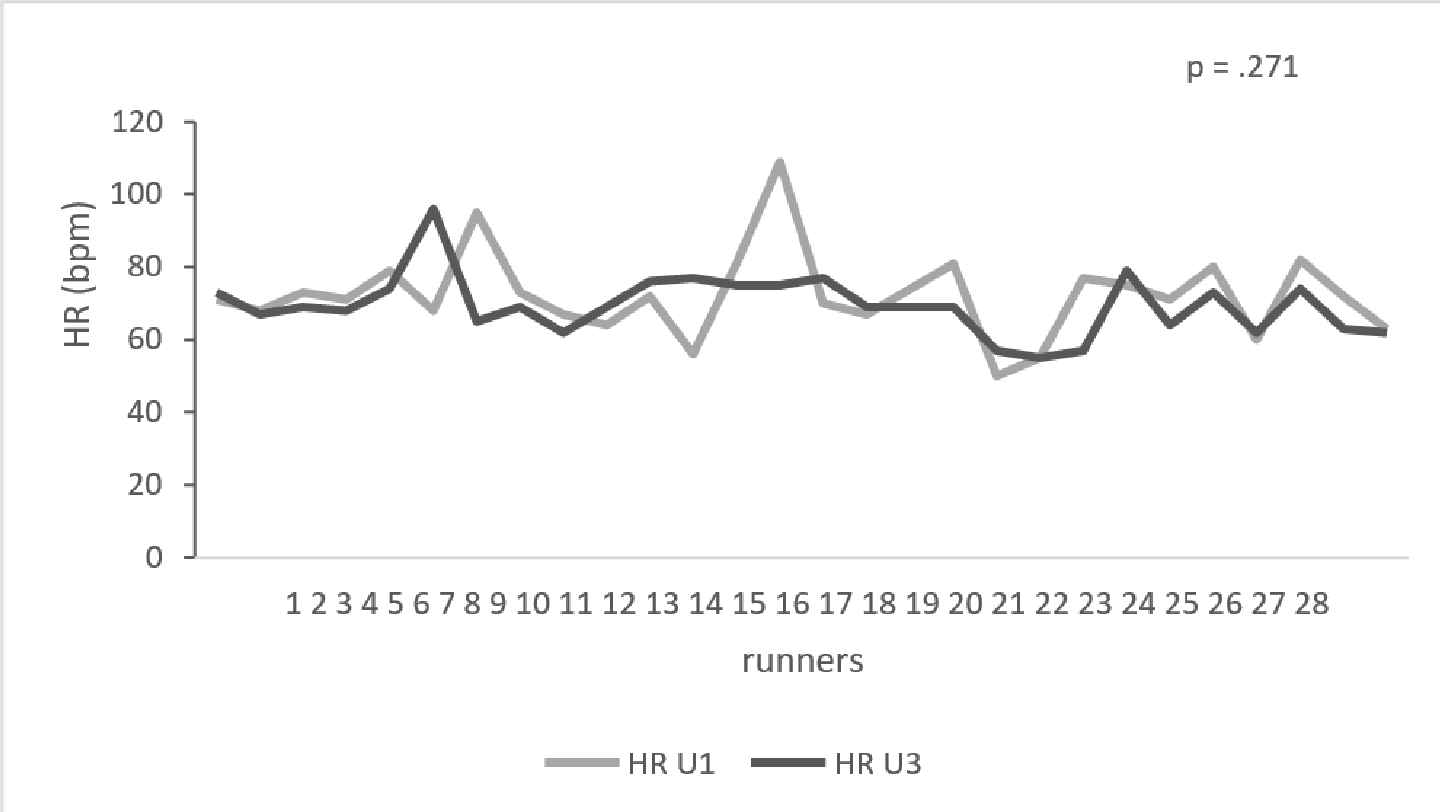

Figure 1

Graph 1 - Mean Value of the Heart rate in U1 and U3

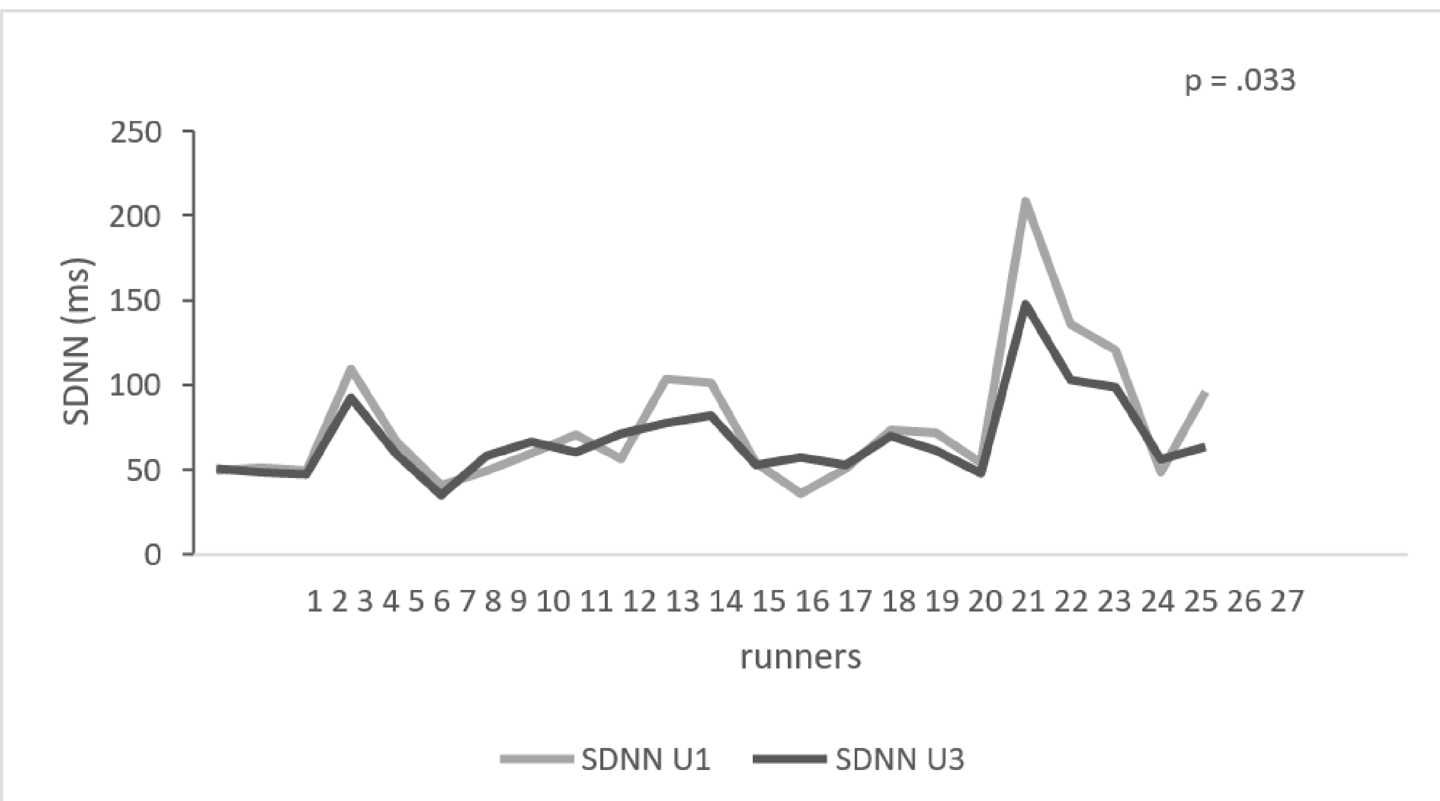

Figure 2

Graph 2 - Mean Value of the SDNN in U1 and U3

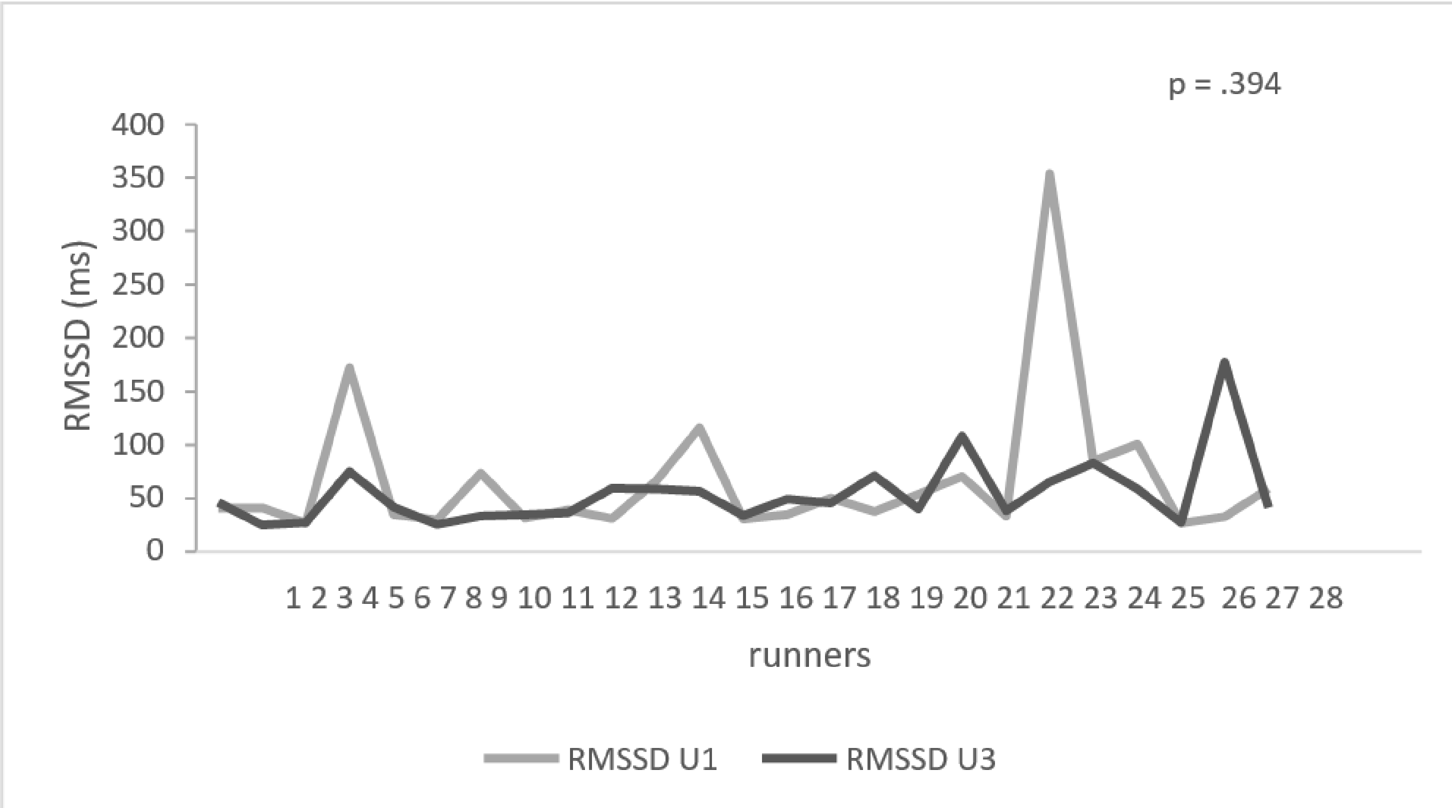

Figure 3

Graph 3 - Mean Value of the RMSSD in U1 and U3

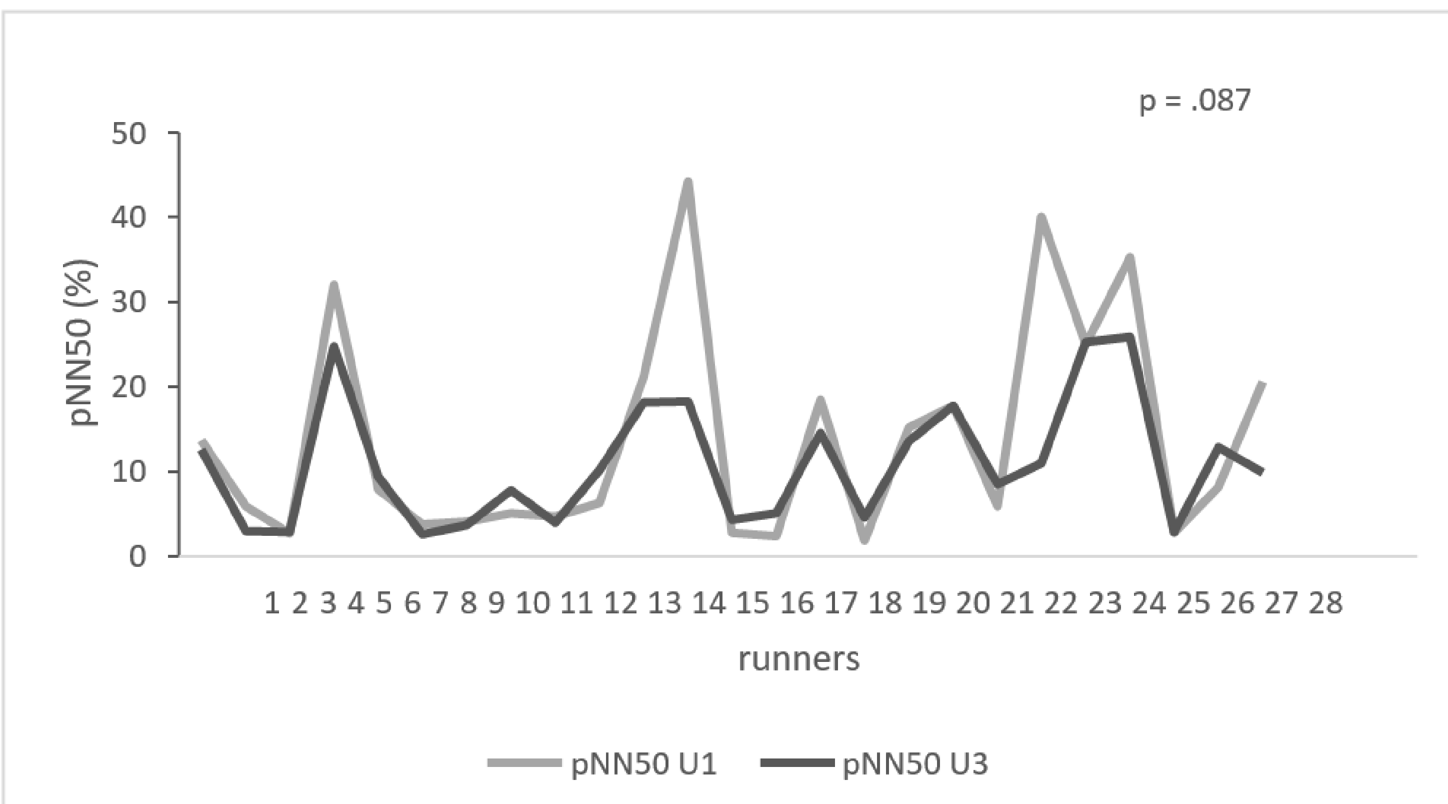

Figure 4

Graph 4 - Mean Value of the pNN50 in U1 and U3