

ORIGINAL ARTICLE
SPORT CARDIOLOGYEffects of a 75-km mountain ultra-marathon
on heart rate variability in amateur runnersAlberto CALLEJA-ROMERO ¹*, Isaac LÓPEZ-LAVAL ¹, Sebastian SITKO ¹, David HERNANDO ^{2, 3},
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ABSTRACT

BACKGROUND: This study examined the effects of a mountain ultra-marathon (MUM) on the activity of the autonomous nervous system through heart rate variability (HRV) monitoring and determined whether this variable related to final performance.

METHODS: Heart rate and HRV were measured in eight male amateur runners (aged 37-60 years). Measurements were recorded before and after the event, in resting conditions, as well as continuously throughout the whole MUM. In addition, percentage (%) of heart rate reserve (HR_{res}) and partial and total times during the race were analyzed.

RESULTS: Average heart rate (HR_{avg}) measured at rest was increased after the event (+37%). Standard deviation of successive differences (SDSD) and the square root of the mean squared differences of successive NN intervals (RMSSD) were reduced after the MUM (-56% and -59%, respectively). There was a positive relationship between the frequency-domain index normalized low frequency power (P_{LFn}) measured at rest before the event and race time (0.79) while there was a negative relationship between race time and the difference in HR_{avg} before and after the event. In the last half of the event, there was a high correlation (Spearman coefficient of correlation >0.9) between race time and the standard deviation of the NN intervals (SDNN) registered during the race.

CONCLUSIONS: Autonomous cardiac regulation can be related to the performance in a mountain ultra-marathon. HRV monitoring could represent a practical tool for the evaluation of the relationship between the autonomous nervous system activity and performance in a mountain ultra-marathon.

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KEY WORDS: Autonomic nervous system; Cardiovascular physiological phenomena; Heart rate; Exercise; Running.

Ultra-endurance competitions have gained considerable popularity during the last years. Trail running events consist of running/walking on mountain trails with positive and negative slopes¹ and may be performed across a great variety of distances. Mountain ultra-marathons (MUM), which are those that exceed marathon distance (>42,195 km), have become especially popular.^{1, 2} These competitions are characterized by their high intensity and

large elevation gains, which are features that have attracted the attention of scientists.² MUMs have been previously used for the study of adaptive responses to extreme competition load and stress in athletes.³

One of the preferred methods for measuring physiological adaptations in participants of ultra-endurance events (UEE) is heart rate variability (HRV).⁴⁻⁶ This variable provides information regarding the autonomous nervous sys-

tem (ANS) function.⁷ Heart rate (HR) monitoring has been one of the most commonly used non-invasive methods in the last years due to its simplicity and convenience.^{4, 6, 8} Recent scientific literature has shown that HR monitoring is useful for evaluating physiological and psychological adaptations to different stressors in endurance sports⁹⁻¹¹ and therefore can be used for assessing training, performance and well-being.

HRV as an indicator of ANS functioning has been previously studied during different stages of the competitive period: before/during breaks,¹² during¹³ or after competition.¹⁴ ANS evaluation through monitoring of basal HR and HRV before a MUM has been previously used to predict performance. One study showed that lower HR in association with a higher vagal tone predicted a better performance in a 690 km MUM, revealed by the correlation between HR and the percentage of consecutive NN intervals larger than 50 ms with respect to the total number of NN intervals (pNN50+).⁹ Nevertheless, resting HRV showed inconsistent results when recreationally trained subjects were compared with those with an extensive training history.¹² Furthermore, differences in athlete's resting HRV could theoretically be attributed to methodological factors such as the time of day at which measurements were taken or the assessment posture. Therefore, more research is required to fully deduce the impact of these methodological considerations.¹⁵ Changes in HRV during a MUM typically show an increase in sympathetic nervous system activation and a decrease in parasympathetic activity, as expected due to the stressful nature of the exercise.¹³ However, vagal tone recovery has been observed before the end of a very long MUM.⁹ After an UEE, HRV analysis showed parasympathetic predominance being gradually restored. This is due to vagal reactivation, which may be modulated by variables such as preceding exercise, training status and others.^{9, 16-18} For this reason, other studies are needed in order to achieve a more comprehensive knowledge about particular variables and their effect on HRV changes after UEE.

Despite scientific evidence regarding ANS modulation before and after an UEE,^{9, 12, 16-18} there are a lot of variables that could affect this process. HRV is associated with numerous external and internal factors,¹⁹ especially in stressful environments (e.g. mountain, substantial altitude variations, etc.)⁹ and, therefore, previous conclusions should be validated.⁹ Furthermore, the analysis and interpretation of HRV during UEE, still remains an important key point in the sports performance field as some studies conclude that breathing and HR are not constant during exercise and

correction factors should therefore be applied before interpreting these results.^{20, 21} The objective of the present study was to assess the activity of the ANS through HRV monitoring before, during and after a 75 km MUM event.

Materials and methods

Participants

Eight male amateur athletes who completed a 75 km MUM participated voluntarily in the present study. The event was the Canfranc-Canfranc (CC), which took place in the Spanish Pyrenees on September 8th, 2018. The study sample represented 11% of the finishing participants. All of them reside and train in their respective cities of residence (all below 1000 m altitude). None of them carried out altitude training camps before the competition.

The main characteristics of the study sample can be seen in Table I. One out of the 8 subjects that made up the study sample was 37 years old, 6 were in an age range between 40 and 48 and 1 subject was 60 years old.

All participants signed a written informed consent and provided data regarding their previous aerobic training experience. The study was designed according to the latest version of the Declaration of Helsinki²² and was previously approved by the Ethical Committee of the autonomous region of Aragon, Spain (ref. N°04/2019).

Inclusion and exclusion criteria

The inclusion criteria were as follows: 1) male gender; 2) aged between 25 and 60 years; 3) participation in a marathon or ultra-marathon in the previous year; 4) non-smoker; 5) familiar with HR monitor attached to the chest during training sessions.

Participants with diagnosed cardiovascular disease or those who presented one or several cardiovascular risk factors, history of surgery or trauma in the six months prior to the event were excluded from participating in the present study.

TABLE I.—Characteristics of the participants.

Variable	N.=8
Age (years)	47.8±7.4 [37-60]
Body mass (kg)	73.6±4.7 [62-79]
Height (cm)	178.4±5.5 [170-185]
Body Mass Index (kg/m ²)	23.1±0.9 [20.5-24.5]
Aerobic Training Experience (years)	8.6±6.0 [4-19]
Mean week running kilometers (km/week)	55.2±8.7 [50-70]

Data are expressed as mean and standard deviation±SD and range (extremes of data set [min-max]).

Procedures

The running distance was 75 km, with a positive elevation gain of 6500 m and a maximal altitude of 2645 m. Figure 1 graphically shows the number of kilometers covered by altitude sections and their corresponding total distance percentage.

The race had 5 feeding points in which solid and liquid meals were provided. The CC Organization tracked and provided the split times of all participants in 8 intermediate points, in addition to the official final time. Profile of the CC, as well as intermediate points where time was registered can be seen in Figure 2.

Evaluation

First, participants completed a questionnaire about their aerobic training history.

Each participant wore a Polar Team Pro Sensor® (Polar Electro, Kempele, Finland) HR chest belt. This system detects heartbeat time occurrences from an ECG recorded at a sampling rate of 1000 Hz.²³ HR chest belts were placed following the recommendations of the manufacturer, below the pectoralis muscles. HR was monitored continuously starting two hours before the MUM and up to thirty minutes after the end. All data were recorded in the memory of the HR chest belt and were downloaded using the software provided by the manufacturer (Polar® Team Manager). RR interval series were obtained and recorded for statistical analysis.

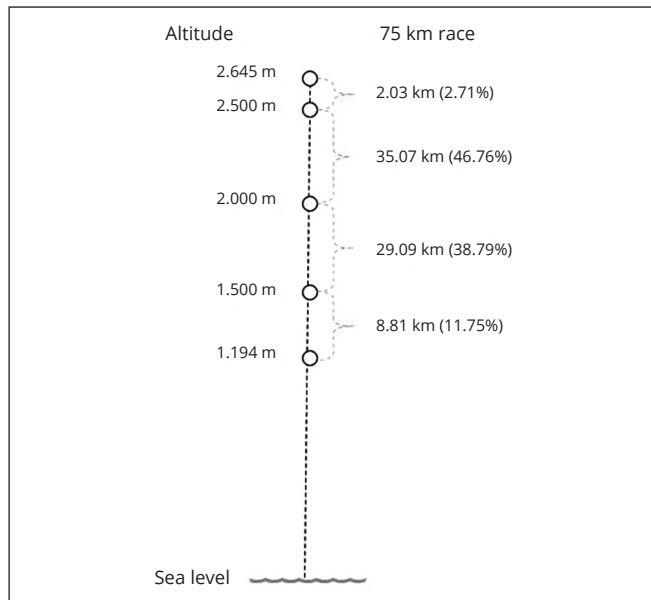


Figure 1.—Race altitude.

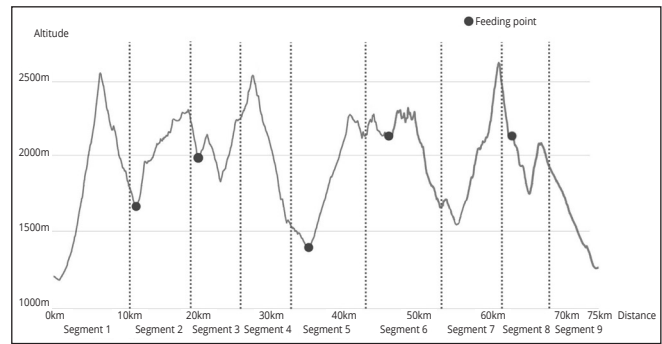


Figure 2.—Race profile.

Ten min HR baseline recording was performed by HR chest belt 2 h prior (PRE) and 20min after (POST) the race in a climate-controlled room (temperature of 23 °C and humidity of 52%) with a calm environment. Participants were in supine position and were instructed to not speak nor move and breathe normally during the recording, following the protocol used in previous studies.^{11, 12} Special emphasis was placed to accurately follow the protocol for PRE and POST recordings. HR was also recorded during the entire race (DURING).

HR data collected from the HR chest belt was completed with information regarding split times during the event (8 points), and the official finishing time. Race times also included provisioning times (Figure 3).

HR and HRV analysis

Maximal HR was estimated using the formula: $HR_{max} = age (208 - 0.7 * age)$.²⁴ The exercise intensity was calculated from the exercise HR (HR_{exe}) as a percentage of the reserve HR (HR_{res}) of each athlete, following the Karvonen formula: $\% HR_{res} = 100 * (HR_{exe} - HR_{rest}) / (HR_{max} - HR_{rest})$.²⁵

Outlier RR intervals were identified based on a time-varying threshold using instantaneous HR variation,²⁶ from which normal-to-normal (NN) interval series were obtained. Time-domain indices were derived from the NN interval series according to the Task Force guideline.^{27, 28}

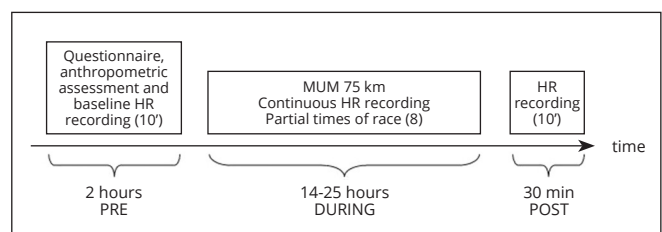


Figure 3.—Schematic representation of the experimental protocol.

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The following indices were computed in each segment (PRE, POST and the 9 segments in which the race was divided): the average HR (HR_{avg}), the standard deviation of the NN intervals (SDNN), the standard deviation of successive differences (SDSD), and the square root of the mean squared differences of successive NN intervals (RMSSD). Frequency-domain indices were obtained from the modulating signal (sampled at 4 Hz) derived from the RR interval series. The methodology used was based on the time-varying integral pulse frequency modulation model, which considers the presence of outlier RR intervals and accounts for the influence of mean heart rate.²⁹ Power in the low and high frequency bands (P_{LF} and P_{HF} , respectively) was established as follows: Low frequency band ranged from 0.04 to 0.15 Hz; high frequency band ranged from 0.15 to 0.5 of the mean HR, with the purpose to capture the spectral components synchronous with respiration, expected to be above the classic limit of 0.4 Hz during exercise. Additionally, the normalized low frequency power ($P_{LFn} = P_{LF}/(P_{LF}+P_{HF})$) was estimated.²⁷

The former HRV indices were computed on the 5 central minutes of the PRE and POST recordings, where stationarity of HRV is assumed. During the race, HRV indices were computed with the following considerations: 1) time-domain indices were computed on each segment of the race; 2) frequency-domain indices were computed on non-overlapping 5-minute windows;³⁰ then, each segment was characterized by the mean and standard deviation of the 5-minute window value indices.

Statistical analysis

Normality was checked with the Kolmogorov-Smirnov Test. Differences between HRV values in the POST and PRE recordings were assessed by Wilcoxon paired ranked test. Spearman correlation was computed between the total race time and HRV indices estimated from the PRE recordings, as well as their variations at the end of the race (POST-PRE). Then, the correlation between estimated HRV indices and times for each segment of the race was analyzed. For the statistically significant cases a *post-hoc* analysis was performed with the Student's *t*-test for paired samples. In all the analysis a P value ($P<0.05$) was considered for statistical significance.

Results

The mean race time was 19.01 ± 3.35 h [14.91 to 24.52] (Table II). Basal HRV values are presented in Table III. PRE and POST measurements showed that after the race

TABLE II.—Description of the race segments.

Segment	Distance (km)	Positive elevation (m)	Negative elevation (m)
1	10.6	1423	953
2	8.5	754	457
3	7.1	896	316
4	7.2	40	1210
5	10.3	1133	394
6	10.5	523	1064
7	7.9	940	590
8	6.6	533	556
9	6.3	36	760

there was a significant increase in the mean HR (+37%, $P<0.05$), and a significant drop in SDSD (-56% $P<0.05$) and RMSSD (-59%, $P<0.05$).

The relationship between race time and HRV indices calculated from both PRE and the difference between POST and PRE (POST-PRE) is presented in Table IV. Basal HRV correlated positively to P_{LFn} and total race time (0.79, $P<0.05$). Regarding the difference between POST-PRE HRV, a negative relationship was observed between HR_{avg} and race time (-0.79, $P<0.05$).

As for the predefined segments, a positive relationship was found between time employed in segments 4, 5, 6, 7 and 8 and the SDNN index of the HRV (Table V). There was also a negative relationship between SDNN and % HR_{res} on the segments 7 (-0.93, $P<0.05$) and 8 (-0.86, $P<0.05$).

Discussion

The present study evaluated the effects of a 75 km MUM on HRV of amateur endurance runners. The main results of the study were that: 1) sympathetic activity was increased after the race, shown by increased HR_{avg} and decreased SDSD and RMSSD; 2) the analysis of P_{LFn} before the race, as an indicator of sympathetic modulation, correlated positively with race time. This means that the higher the sympathetic activity before the race, the more time was needed to complete it; 3) race time correlated negatively with the difference between before and after race resting HR_{avg} . In other words, slower participants showed less increase in HR_{avg} at the end of the race in comparison to their HR_{avg} before the race; 4) lastly, another interesting finding was detected as a result of the continuous recording throughout the whole race: there was a high correlation (Spearman coefficient of correlation >0.9) between race time during the second half of the event (segments 4 to 8 out of 9) and the SDNN registered during these segments, meaning that

TABLE III.—HRV variables during the PRE and POST recordings.

	HR _{avg} (bpm)	SDNN (ms)	SDSD (ms)	RMSSD (ms)	PLFn (n.u)	PHF (ad) x e ⁻⁴
PRE	51±2	43±25	32±25	32±25	0.50±0.25	3.4±4.0
POST	70±13	25±21	14±12	13±12	0.65±0.25	0.5±1.4
P value	0.0156*	0.0781	0.0156*	0.0156*	0.4688	0.4688

Data are expressed as mean and standard deviation (±SD).

Heart rate variability (HRV) variables during the baseline recording (PRE) and after race recording (POST), and P value obtained by Wilcoxon paired ranked test are displayed with *, P values<0.05.

HRavg: average heart rate; SDNN: standard deviation of the NN intervals; SDSD: standard deviation of successive differences; RMSSD: square root of the mean squared differences of successive NN intervals; PLFn: normalized power in the low frequency bands in normalized units; PHF: power in the high frequency bands.

TABLE IV.—Spearman correlation coefficient between the total time of the race and each HRV index during the PRE recording and difference between the POST and PRE recordings.

	HR _{avg} (bpm)	SDNN (ms)	SDSD (ms)	RMSSD (ms)	PLFn (n.u)	PHF (ad) x e ⁻⁴
PRE	-0.21	-0.14	-0.46	-0.46	0.79*	-0.64
POST-PRE	-0.79*	-0.03	0.18	0.18	-0.54	0

HRavg: average heart rate; SDNN: standard deviation of the NN intervals; SDSD: standard deviation of successive differences; RMSSD: square root of the mean squared differences of successive NN intervals; PLFn: normalized power in the low frequency bands in normalized units; PHF: power in the high frequency bands.

*Statistically significant correlations.

TABLE V.—Spearman correlation coefficient between SDNN and the time of each segment and running intensity calculated from the running heart rate (HR_{exe}) as a percentage of the reserve heart rate (HR_{res}).

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7	Segment 8	Segment 9
Time	-0.21	0.61	0.68	0.79*	0.93*	0.93*	0.93*	0.89*	0.32
Intensity	-0.07	-0.36	-0.61	0.07	-0.75	-0.46	-0.93*	-0.86*	-0.25

*Statistically significant correlations.

less sympathetic activation resulted in a slower pace in the second half of the event, or *vice versa*.

The increase of HR_{avg} (+37%) and also the reduction in time-domain variables of the HRV such as SDSD (-56%) and RMSSD (-59%) observed after the end of the race are in line with current scientific evidence regarding cardiovascular control after exercise. In previous studies, such as Gratze *et al.*,¹⁶ a 27% increase in the HR_{avg} was observed one hour after the end of an Ironman (10.98 hours of racing). Similarly, Murrell *et al.*³¹ reported a 35% HR_{avg} increase 3 to 5 hours after the end of a mountain marathon (4.35 hours of racing). Considering this, the 37% HR_{avg} increase after MUM observed in the current study is consistent with previous findings that suggest that sympathetic activation due to high intensity endurance exercise can be observed after the end of the activity (30 minutes in this case). Likewise, the decrease in SDSD, which represents short-term variability (SDNN),³² and the decrease in RMSSD after endurance events have been reported previously such as in the study performed by Foulds *et al.*,¹⁸ with observed decreases of 52% in SDNN and 42% in RMSSD after ultra-marathons. This evidence suggests that the homeostasis disruption produced by high intensity

endurance events induces changes in the ANS, a finding that reflects the increased sympathetic modulation during this type of exercise.¹⁸ This can be observed even after the exercise period has finished. These changes, as an acute effect of ultra-endurance efforts, may play a role in cardiac adaptations in this type of exercise.^{13, 33}

Regarding the basal values studied before the event, the HRV analysis through frequency-domain methods established a positive correlation between race time and P_{LFn} . On a more practical level, this meant that the participants with higher P_{LFn} values before the event performed worse (0.79, $P<0.05$). One possible cause of this relationship could be the precompetitive anxiety, which has been previously linked to changes in HRV towards sympathetic activation in athletes. Cervantes *et al.*³⁴ reported that the low frequency (LF) components were higher in swimmers during competitive periods than during training periods. One possible cause of this could be that stress management before the event may have influenced performance. These results are in line with previous evidence that suggests a moderate relationship ($r=0.10$) between cognitive anxiety and sports performance, as described by Woodmand and Hardy³⁵ in their meta-analysis of 48 studies. Although other more re-

cent studies have not established a statistically significant relationship between performance and cognitive anxiety,³⁶ the results of the present study could be explained by the hypothesis proposed by Raglin JS,³⁷ who suggested that the relationship between precompetitive anxiety and performance could be influenced by several different factors such as the sports modality, self-confidence and even the negative or positive perception of anxiety.³⁵ Considering all of this, the results of our study suggest that the participants with the lowest LF power before the event (which has been linked to optimal stress management before competitions) performed better during a 75 km MUM.

The correlation obtained between the difference in POST-PRE HR_{avg} and race time could be contextualized by considering that a significant relationship between the SDNN during the second part of the event (segments 4 to 8) and race time was also found. Assuming SDNN as an indicator of HRV,³⁸ this result shows that the slowest participants during the last part of the event (when compared to total race time), also showed lower sympathetic activation during the second half and reported lower POST HR_{avg} when compared to PRE HR_{avg}. Regarding these results, Franco *et al.*³⁹ observed a negative correlation between the HR increase during a marathon and race time ($r=-0.5$; $P=0.05$), with slower athletes showing lower sympathetic activation during the race as evidenced by a lower increase in HR. Taking into account the duration of the race analyzed in the current study (average of 19.01 h), self-pacing could produce a variation in the physiological responses of the athlete. Therefore, a possible explanation for this correlation is the fact that the participants with worse performance in the second half of the event were also characterized by lower relative intensities during this part. A significantly higher SDNN in segments 5 to 8 and lower HR_{res} in the final part of race supports this explanation. Rudfeldt *et al.*⁹ observed a recovery in vagal tone after a 690k ultra-marathon, hypothesizing that this phenomenon could be explained by the length of the race. The positive correlation between SDNN and race time found in the present study could add a new factor to this hypothesis: pace reduction during the event could influence vagal tone recovery before the end of the race. The increasingly lower intensities seen in the second half of the race could explain the reduced vagal tone recovery that was observed.

Limitations of the study

This study was conducted with a small sample size. Despite this, we consider that a study sample that represented 11% of the total race finishers reports meaningful informa-

tion on this type of extreme conditions. Regarding HRV analysis in long distance athletes, there is enough scientific evidence to rely on for its interpretation during resting, however there is a lot of controversy around its interpretation during an effort. Future studies should emphasize on the interpretation of ANS through HRV analysis during exercise to confirm or clarify the conclusions of this study.

Conclusions

HRV analysis provides valuable information concerning the activity of the ANS in amateur runners before, during and after a 75 km MUM.

According to the results of this study, increased sympathetic modulation before the race, denoted by P_{LFn} analysis, predicts subsequent worse performance. Sympathetic activity is increased during a MUM and this can be observed even at the end of the race by an increased HR_{avg} and decreased SDDSD and RMSSD. Despite this, lower sympathetic activation resulted in a slower pace during the second half of the race, indicated by a high correlation between SDNN and race time during this segment.

Monitoring HRV in endurance athletes is, therefore, a useful and affordable tool for the assessment of cardiac autonomic regulation linked to race performance.

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