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ORIGINAL

ONE YEAR FOLLOW-UP WITH HEART RATE VARIABILITY IN TRAIL RUNNERS

UN AÑO DE SEGUIMIENTO CON VARIABILIDAD DE LA FRECUENCIA CARDIACA EN TRAIL RUNNERS

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ABSTRACT

This study aims to analyze HRV measures to provide reference values for Ultra-Trail Running (UTR) athletes. Sixteen Chilean UTR (12 men and 4 women) were monitored over one year follow up. These are baseline records for each participant over a full year, during which they maintained their usual training, competitive, and rest activities. The variable use to evaluate the parasympathetic activity was, the square root of the mean value of the sum of the squared differences of all successive RR intervals (RMSSD). Additionally, Stress Score (SS) was calculated from the Poincaré's scatter plot as an indicator of sympathetic activity. This study provided baseline HRV values for UTR athletes through a percentile distribution, both in time domain measurements and the Poincaré scatter plot, for a population of UTR athletes from daily 5-minute baseline records in the supine position upon waking up.

KEYWORDS: Percentiles, Heart rate variability, Training load, Ultra trail running

RESUMEN

Este estudio tuvo como objetivo analizar las medidas de variabilidad de la frecuencia cardíaca (VFC) para proporcionar valores de referencia en atletas de Ultra-Trail Running (UTR). Dieciséis UTR chilenos fueron monitoreados con registros basales al despertar de 5 minutos durante un año de seguimiento, tiempo en el cual, mantuvieron sus actividades habituales de entrenamiento, competición y descanso. Como variable para evaluar la actividad parasimpática la RMSSD (raíz cuadrada de la media de las diferencias de la suma de los cuadrados entre intervalos RR adyacentes) fue analizada. Además, se calculó el Stress Score (SS) como indicador de la actividad simpática. Los datos aportados proporcionan valores de referencia de VFC para UTR a través de una distribución de percentiles, que pueden ser particularmente útiles cuando la VFC se utiliza para el control de las cargas de entrenamiento en atletas de UTR.

PALABRAS CLAVES: Percentiles, variabilidad de la frecuencia cardíaca, carga de entrenamiento, Ultra trail running

INTRODUCTION

A trail running (TR) event is defined as a race along unpaved trails, with elevation changes and varies in distance from 15 to 42 km (Zaryski & Smith, 2005). An ultra trail running (UTR) event is defined as a race along unpaved trails with elevation changes and distances over 42 km to 160 km (Costa, Gill, Hankey, Wright, & Marczak, 2014; Millet et al., 2011; Zaryski & Smith, 2005).

The interest in controlling training load (TL) in UTR athletes aims to monitor their adaptation (Bourdon et al., 2017), and must distinguish between two types of training load. The first is the managed load/external training load (ETL), and the second is how each subject assimilates and responds to that managed load, known as the internal training load (ITL) (Halson, 2014; McLaren et al., 2018). One method for monitoring TL is heart rate variability (HRV), which is a non-invasive instrument that identifies the ITL (Sandercock, Bromley, & Brodie, 2005) as well as the involvement of the autonomic nervous system (ANS) in states of overtraining and fatigue (Buchheit, 2014; Buchheit et al., 2013; Nieto-Jiménez, Pardos-Mainer, Ruso-Álvarez, & Naranjo-Orellana, 2020; Sarabia, Cruz-Torres, & Naranjo-Orellana, 2012).

In the HRV, time variations that occur between RR intervals are analyzed (Task-Force, 1996). There are many measurements used to analyze these variations. One of the most common statistics in the field of sport for evaluating parasympathetic activity is the root mean square of the successive differences between RR intervals (RMSSD) (Buchheit, Papelier, Laursen, & Ahmaidi, 2007; Halson, 2014; Task-Force, 1996). It is often expressed as its natural logarithm or LnRMSSD (Buchheit, 2014), which allows for parametric analysis of the data (Michael, Jay, Halaki, Graham, & Davis, 2016) and a lower day-to-day variation than other HRV indices.

Another HRV analysis is the Poincaré scatter plot, in which each RR interval is plotted against the previous one, emerging an ellipse-shaped scatter plot. This analysis provides a useful and fast way to obtain information about the sympathetic and parasympathetic equilibrium (Tulppo, Makikallio, Takala, Seppanen, & Huikuri, 1996) through the transversal (SD1) and longitudinal (SD2) diameters of the graph. SD1 behaves proportionally to the parasympathetic stimulus, while SD2 behaves inversely to the sympathetic activity.

Both Poincare magnitudes changes in the same direction when changes in the ANS occur, both during the exercise and recovery, making it difficult to interpret a quotient that indicates a relation between them. As a result of this, the stress score (SS), which is the inverse of SD2 multiplied by 1000, was proposed as a direct indicator of sympathetic activity (Naranjo, De la Cruz, Sarabia, De Hoyo, & Dominguez-Cobo, 2015). The quotient between SS and SD1 was proposed by these authors as an indicator of the relationship between the sympathetic and parasympathetic system (S-PS Ratio).

For individual sports, Nieto-Jiménez et al. (2020) reported the usefulness of daily LnRMSSD and LnSS wake-up records for monitoring the sympathetic-parasympathetic status during a 16-week competitive period for a female UTR athlete and a 7-month training period for an Ironman athlete (Nieto-Jiménez, Ruso-Álvarez, Pardos-Mainer, & Naranjo Orellana, 2020). Other authors have used the coefficient of variation (CV) of this variable for daily monitoring. The CV in professional athletes fluctuates between 4 and 9% of the LnRMSSD during training blocks in elite rowers (Plews, Laursen, Stanley, Kilding, & Buchheit, 2013) and elite triathletes (Le Meur et al., 2013; Plews, Laursen, Kilding, & Buchheit, 2012).

One of the problems when using CV values for tracking and monitoring HRV in athletes is the scarcity of sport-specific reference values. Reference values have been published for young and healthy subjects (athletes and non-athletes) with 30-minute records, providing percentile distributions by groups (Marina Medina, Blanca de la Cruz, Alberto Garrido, Marco Antonio Garrido, & José Naranjo, 2012) or for professional football players (Naranjo et al., 2015). However, we have not found studies in UTR athletes that have provided short record reference values.

This study aims to analyze the RMSSD and SS in daily and baseline measurements during 365 days, both in direct values and in their natural logarithms, to provide reference values in UTR athletes.

MATERIAL AND METHODS

Sixteen Chilean UTR athletes (12 men and 4 women) in the national amateur category (age 33 ± 3 years; size 169 ± 5 cm; weight 68.5 ± 2 kg) were monitored over one year. The subjects (men and women) systematically trained at least 12 ± 2 hours per week and participated in three UTR competitions during the follow-up period. The training sessions were planned according to mesocycles, using the distance covered and the accumulated training time as a quantification of the load performed.

The data obtained comes from a total of 3066 records from male athletes and 652 records from female athletes. These are baseline records for each of the athletes over a full year, during which they maintained their usual training, competitive, and rest activities.

Before the study, all the athletes completed a medical questionnaire to rule out any treatment, cardiovascular or other disorders that could alter the state of the autonomic nervous system.

HRV data recording procedure

HRV measurements were taken upon awakening in the supine position for five minutes. The first instrument was a Polar V800 heart rate monitor with a H10 HR Sensor chest strap (Polar Inc., Kempele, Finland), validated for HRV measurements (Giles, Draper, & Neil, 2016). RR time series were downloaded using the Polar FlowSync app (version 2.6.2). The second instrument used was the Elite HRV mobile phone app (version 4.3.0) validated for HRV measurements (Perrotta, Jeklin, Hives, Meanwell, & Warburton, 2017), with an H10 HR Sensor chest strap, after which the RR series was exported in .txt format to email (C. Nieto-Jimenez et al., 2020). The records were then analysed with Kubios HRV software (version 3.1.0, University of Eastern Finland, Kuopio, Finland). Each recording was previously inspected to detect the possible presence of artefacts and/or anomalous beats, applying if necessary the corresponding filters offered by the software itself, without exceeding in any case the medium filter.

As a time domain variable to assess parasympathetic activity, the RMSSD in ms (Task-Force, 1996) and its respective natural logarithm (Ln) were calculated. On the other hand, from the SD2 of the Poincaré scatter plot (Tulppo et al., 1996) the stress index (SS) (Naranjo et al., 2015) was calculated as an indicator of sympathetic activity, also its Ln was calculated. Finally, the ratio between SS and SD1 informed us of the ratio between sympathetic and parasympathetic (S-Ps Ratio) (Naranjo et al., 2015).

Statistical Analysis

Data are presented as mean and standard deviation (SD) with the corresponding coefficient of variation (CV). For each of these variables, a distribution analysis was performed, separating the population by sex. First, the 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles were calculated. Secondly, separating the measurements by subject, a graphical analysis of the distributions of LnRMSSD and LnSS was performed using box plots to analyse between-subject heterogeneity. Each box plot was constructed according to the convention of McGill et al (McGill, Tukey, & Larsen, 1978) where the box represents the interquartile range, the centre line reflects the median, and the whiskers extend 1.5 times the range from each of the edges. Those measurements outside the range of the whiskers are plotted with a dot representing atypical data.

RESULTS

Tables 1 and 2 present descriptive statistics for the entire population of athletes, differentiated by sex. Table 1 presents the mean, standard deviation, and coefficient of variation (CV) values, and Table 2 presents the percentiles of the HRV variables.

Table 1. Mean values, standard deviation, and coefficient of variation (CV) to sex.

	Men			Women		
	Medium	**SD**	**CV**	**Medium**	**SD**	**CV**
Medium RR	1147,6	175,3	15%	1144,9	254,8	15%
RMSSD	72,4	40,3	43%	89,9	53,9	38%
LnRMSSD	4,2	0,5	11%	4,3	0,6	10%
SD1	51,4	28,6	43%	63,8	38,2	38%
SD2	138,0	60,8	34%	145,8	85,8	39%
SS	8,5	3,6	41%	9,1	5,1	35%
LnSS	2,1	0,4	16%	2,1	0,5	16%
Ratio-S/PS	0,25	0,25	87%	0,24	0,30	98%

RMSSD: square root of the mean value of the sum of the squared differences of all successive RR intervals. LnRMSSD: natural logarithm of the RMSSD; SD1: transverse axis of the Poincaré scatter plot; SD2: longitudinal axis of the Poincaré scatter plot; SS: stress score; LnSS: natural logarithm of the SS; S-Ps ratio: sympathetic-parasympathetic ratio; CV: coefficient of variation. SD: standard deviation.

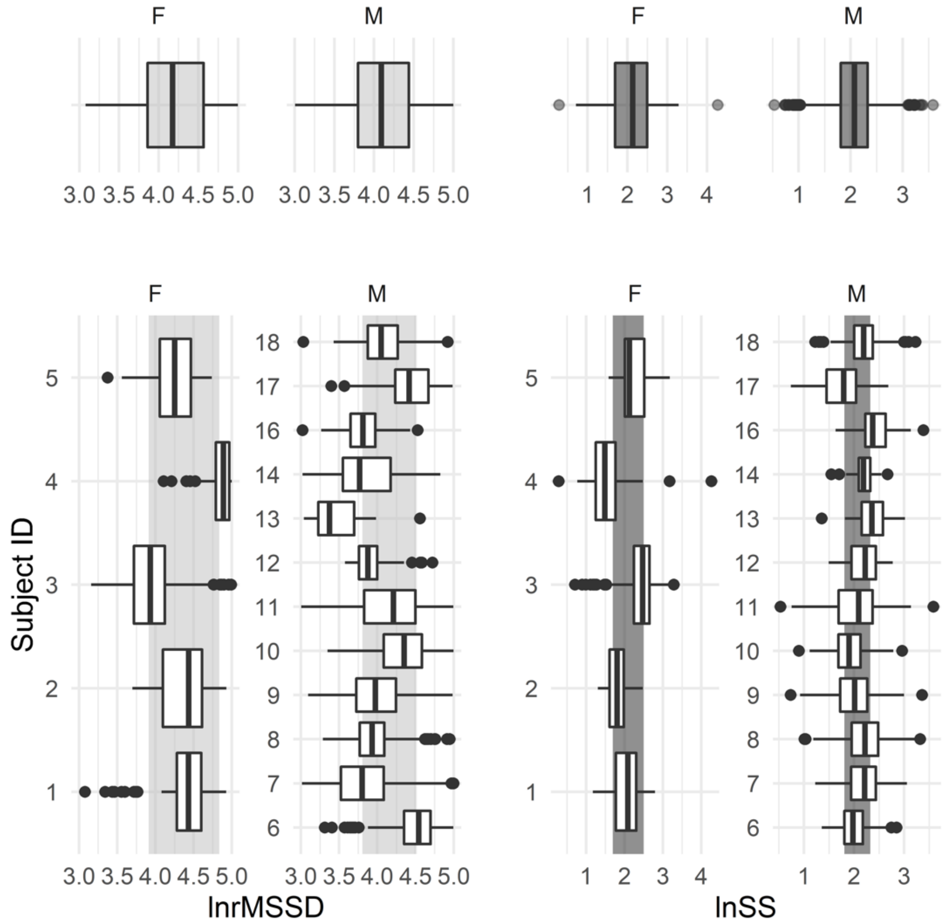
Table 2. Percentiles of the HRV variables differentiated by sex

		Percentiles						
		5	**10**	**25**	**50**	**75**	**90**	**95**
RMSSD	**Women**	32,6	39,3	49,9	75,1	125,9	160,0	181,9
	Men	28,4	33,4	45,0	61,6	90,4	124,0	149,3
LnRMSSD	**Women**	3,5	3,7	3,9	4,3	4,8	5,1	5,2
	Men	3,3	3,5	3,8	4,1	4,5	4,8	5,0
SD1	**Women**	23,1	27,9	35,4	53,3	89,1	113,6	129,2
	Men	20,1	23,6	31,9	43,7	64,0	88,0	105,9
SD2	**Women**	57,6	66,1	82,5	118,6	183,8	270,6	321,7
	Men	66,8	76,3	97,6	126,0	163,7	212,0	253,0
SS	**Women**	3,1	3,7	5,4	8,4	12,1	15,1	17,4
	Men	4,0	4,7	6,1	7,9	10,2	13,1	15,0
LnSS	**Women**	1,1	1,3	1,7	2,1	2,5	2,7	2,9
	Men	1,4	1,6	1,8	2,1	2,3	2,6	2,7
Ratio-S/PS	**Women**	0,03	0,03	0,07	0,16	0,32	0,53	0,65
	Men	0,04	0,06	0,10	0,18	0,31	0,50	0,69

Percentiles 5, 10, 25, 50, 75, 90, and 95 are included. SD1: Transverse axis of the Poincaré plot SD2: Longitudinal axis of the Poincaré plot SS: Stress Score; LnSS: natural logarithm of the SS; S/Ps Ratio: Sympathetic-Parasympathetic Ratio; RMSSD: Square root of the mean value of the sum of the squared differences of all successive RR intervals LnRMSSD: natural logarithm of the square root of the mean value of the sum of the squared differences of all the successive RR intervals.

Figure 1 shows the distribution of the LnrMSSD and LnSS variables for each sex and each subject. The distributions of both variables and sex are shown in the upper box. In the box diagram, the points represent outliers. The shaded band represents the inter-quartile range of each variable and sex, from quartile 1 (25th percentile) to quartile 3 (75th percentile).

Figure 1. Probability distribution of lnrMSSD and lnSS variables according to sex



The first and second columns show the LnrMSSD distributions for women and men respectively, and the third and fourth columns show the LnSS distributions. The box diagram corresponds to the range between quartile 1 and 3, known as the IQR, the whiskers in each box correspond to the values observed up to 1.5 times the IQR above quartile 3 and below quartile 1. The dots reflect the data observed outside this range and are determined as outliers.

DISCUSSION

The main contribution of this study was to provide percentile data of HRV, both in time domain measurements and the Poincaré scatter plot, for a population of UTR athletes with 5-minute baseline records in the supine position upon waking up. The sample was composed of athletes from the same sports team with a training schedule of one year (3718 records).

Since the Task Force (Task-Force, 1996) recommends using the RMSSD as an estimate of short duration components we selected this variable as a measure of parasympathetic activity along with SS as an index of sympathetic activity (Naranjo et al., 2015). Although the Task Force provided reference values, these correspond to patients and cannot be used to assess athletes (Marina Medina et al., 2012). For example, the reference value for the RMSSD of 27 ±12 ms (Task-Force, 1996) in our distribution would be below the 5th percentile.

In the literature, we have found three studies, with different data acquisition methodologies, that have reported reference values in different populations. Medina et al (Marina Medina et al., 2012) studied a sample of 200 athletic verses non-athletic subjects between 18 and 24 years old with 30-minute records. In their study, male athletes and non-athletes presented RMSSD values of 63 ms and 44 ms respectively at the p50 percentile. For females, the values were 80 ms for athletes and 41 ms for non-athletes. Additionally, Sammito and Böckelmann (Sammito & Bockelmann, 2016) used 24-hour records for men and women between 30 and 40 years of age and their average RMSSD values were 40 ms and 36 ms respectively.

The only study we have found that provided percentiles over a full season with 5-minute records was in elite professional soccer players (Naranjo et al., 2015), which reported RMSSD values of 85 ms at the 50th percentile. In our study (table 2) we observed RMSSD values of 61 ms and 75 ms in men and women respectively for the same percentile, which are very close to those reported by Medina et al. (Marina Medina et al., 2012) for university athletes.

Regarding the methodology, our study is in line with that of Naranjo et al. (2015) as they are short measurements before training. However, Naranjo et al. (2015) only assessed one measurement per week and they were not in baseline conditions upon awakening. Apart from this different condition (basal or non-basal) between the two studies, we believe that the differences in data between our male runners and the footballers in Naranjo et al. (2015) were due to the type of population, sporting discipline, and ages of the subjects.

Studies have reported that the more trained the subjects, the higher the RMSSD at baseline (Nieto-Jiménez, Pardos-Mainer, et al., 2020), this is what we could deduce by looking at our records of female athletes at p50 (RMSSD=75 ms) and comparing them with the (Marina Medina et al., 2012) data on untrained women (RMSSD=41 ms) and Sammito and Böckelmann (2016) for the 30 to 40 year age group (RMSSD=36 ms). Despite the above, we have not found any other studies in the literature that have reported baseline values using percentiles in UTR women. Our percentile distribution for RMSSD would indicate that records below 28 ms in men and 32 ms in women would not be normal baseline measurements for a UTR athlete.

In a Poincaré scatter plot the increase in SD1 means increased parasympathetic activity, while increased SD2 means decreased sympathetic activity (Tulppo et al., 1996). Our p50 values in men for SD1 (43 ms) were lower than those of Naranjo et al. (2015) (60 ms), higher than those of Sammito and Böckelmann (2016) (26 ms), and similar to those of the sports subjects of Marina et al (47 ms)(Marina Medina et al., 2012). Women also presented values of SD1 (53 ms) higher than Sammito and

Böckelmann (2016) (29 ms) and similar to those of Marina et al, (58 ms).(Marina Medina et al., 2012).

For SD2, following the methodology of Naranjo et al. (2015), we calculated the SS as the inverse of SD2 multiplied by 1000, as a direct indicator of sympathetic activity at rest in trained subjects (Naranjo et al., 2015). These authors proposed a risk zone from the 90th percentile and defined an alarm zone between the 75th and 90th percentile (Naranjo et al., 2015), which is equivalent to an SS between 8 and 10; whose natural logarithms (Ln) would be 2.08 and 2.30. If we use this same criterion, in this sports population a limit of normality of the SS could be established at 13 for men and 15 for women (2.6 and 2.7 respectively for LnSS), with an alarm zone between 10 and 13 (2.3 to 2.6 for LnSS) or between 12 and 15 (2.5 to 2.7 for LnSS) respectively.

Although Medina et al (2012) (Marina Medina et al., 2012) does not provide SS data because it was performed previously to the description of this variable, we calculated its value from the percentiles of SD2, obtaining SS values between 4.2 (LnSS=1.4) and 14.5 (LnSS=2.7) for male sportsmen. The values reported by Naranjo et al. (2015) for SS ranged from 3.7 (LnSS=1.3) to 10.1 (LnSS=2.3). Our data presented SS values between 4 (LnSS=1.4) and 15 (LnSS=2.7), quite similar to those of Corrales et al. (2012). In the case of female athletes, SS data from Corrales et al. (2012) were between 4 and 14.5 (1.4 to 2.7 for LnSS), while ours were between 3 and 17.4 (1.1 to 2.9 for LnSS).

In short, our RMSSD and SS values are similar to those reported by Marina et al (2012) (Marina Medina et al., 2012) for university sportsmen, although with somewhat greater differences for women. However, the population of elite football players reported by Naranjo et al. (2015) had higher RMSSD values and lower SS values than ours; probably because of their higher competitive level.

There is a case study (Nieto-Jiménez, Pardos-Mainer, et al., 2020) that used the LnSS to follow a UTR runner during a 16-week season and reported average weekly LnSS values below 2.23, which for our percentile distribution would be between p50 and p75 and therefore would correspond to values in normal ranges without signs of fatigue or over-training. The value of the SS (and the LnSS) will indicate if the sympathetic tone observed in the basal situation is within the expected range for complete recovery or, on the contrary, the result of secondary alterations due to stress caused by the previous load. To carry out this type of monitoring to control training loads, it is essential to have reference values for this type of sporting discipline.

Naranjo and collaborators (Naranjo Orellana, de la Cruz Torres, Cachadiña, de Hoyo, & Cobo, 2015) described the S-PS Ratio as a useful tool to monitor changes in the autonomic balance from conventional HRV variables. Analogous to the SS, they established the p90 of the sample (ratio of 0.3) as a limit to consider the ratio altered at rest. In our distribution, this limit would correspond to values of 0.50 and

0.53 for men and women respectively. A ratio higher than these values at rest would indicate an altered autonomic balance due to a higher sympathetic activity or to a lack of recovery of the parasympathetic activity in rest. This behavior of the sympathetic-parasympathetic balance depends on the characteristics of the load carried out (ETL) and on how each subject assimilates and responds to that specific load at a given moment (ITL).

Finally, Figure 1 shows the distribution of the individual subjects' values within the framework of the behavior for each group. This figure shows how useful this distribution of normal values will be when applied to the monitoring of TL in UTRs (or similar modalities) by analyzing a 5-minute baseline record of HRV daily. As it is a non-invasive technique, easy to apply and of a duration that does not interfere with the daily routine, it becomes a tool to be taken into account to assess the degree of recovery of the athlete on a daily basis with respect to previous loads and, at the same time, to know in what conditions he/she faces a new work session.

One limitation of this study could be the low sample size, but as it is a group of athletes belonging to the same training team, a very valuable homogeneity is achieved in the subjects and, on the other hand, as it is a one-year follow-up, the total number of records is more than sufficient for it to be statistically valid.

CONCLUSIONS

The data provided reference HRV values for UTR athletes through a percentile distribution, which may be particularly useful when HRV is used to monitor training loads an endurance athlete over a year of follow-up. Daily 5-minute basal recordings appear to be a useful way to monitor the state of sympathetic-parasympathetic balance prior to training sessions.

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