ORIGINAL ARTICLE

Pre- and Post-Endurance Exercise Gender Differences Between Ultra Marathon Athletes

Diferencias de sexo entre deportistas de ultramaratón preesfuerzo y posesfuerzo

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ABSTRACT

Background: The presence of women in ultramarathon competitions has become increasingly frequent. Physiological adaptations and response to maximum exercise are influenced differently according to gender.

Objectives: The aim of this study was to evaluate the differences observed in ultramarathon or ultratrail athletes (mountain races over 42 km), at rest (physiological adaptations) and post-endurance exercise [exercise-induced cardiac fatigue (EICF)], stratified by training parameters.

Methods: Twenty-five athletes (6 women) who participated in the Mendoza crossing race (55 km in the mountains) were evaluated before and after the end of the race using Doppler echocardiography and myocardial deformation techniques (post-processing). Training and running parameters were documented with sports watches. Immediate post-endurance exercise blood withdrawal was performed to document variables associated with cardiac fatigue.

Results: The race was completed by 24 athletes, 19 men (42±12 years) and 5 women (38±4 years). Women and men presented similar training loads and completed the race with no difference in time. Decreased left myocardial function parameters (EICF) were observed in 50% of men and 5% of women.

Conclusions: Despite no differences in training characteristics were found, less baseline physiological adaptation and a lower incidence of EICF was observed in women.

Key words: Ventricular function - Cardiac Imaging Techniques / methods - Cardiomegaly, Exercise-Induced – Fatigue - Heart – Women

RESUMEN

Introducción: La presencia de mujeres en las competencias de ultramaratón se observa cada vez con más frecuencia. Las adaptaciones fisiológicas y la respuesta al máximo esfuerzo se diferencian influenciados por el sexo.

Objetivos: Evaluar las diferencias observadas en los deportistas de ultramaratón o ultratrail (carreras de montaña de más de 42 km) en reposo (adaptaciones fisiológicas) y en el post esfuerzo [fatiga cardíaca inducida por el ejercicio (FCIE)], estratificado por parámetros de entrenamiento.

Material y métodos: Se reclutaron veinticinco deportistas (mujeres, n=6) que participaron de la carrera cruce Mendoza (55 km en montaña) siendo evaluados antes y después de la finalización de la carrera mediante ecocardiografía Doppler y técnicas de deformación miocárdica (postprocesamiento). Mediante relojes deportivos se documentaron parámetros durante el entrenamiento y la carrera. Se realizó extracción de sangre post esfuerzo inmediato para documentar variables asociadas a fatiga cardíaca.

Resultados: Completaron la carrera 24 deportistas, 19 hombres (42±12 años) y 5 mujeres (38± 4 años). Las mujeres presentaban parámetros similares de entrenamiento y completaron la prueba sin diferencia en tiempos respecto a los hombres. Se observó disminución de los parámetros de función miocárdica izquierda (FCIE) en el 50% de los hombres y 5 % de las mujeres.

Conclusiones: A pesar de no encontrar diferencias en las características del entrenamiento, se observó en las mujeres menos adaptación fisiológica basal y menor incidencia de FCIE.

Palabras clave: Función ventricular - Técnicas de Imagen Cardíaca/métodos - Cardiomegalia Inducida por el Ejercicio - Fatiga - Corazón – Mujeres

INTRODUCTION

The heart exhibits several physiological adaptations to training: heart rate (HR) decreases at rest due to increased vasovagal tone, end-systolic and end-diastolic volumes as well as stroke volume increase, and contractility decreases. The purpose of all these physiological adaptations is to have greater contractile reserve, and to increase up to 5 times cardiac output (CO) during strenuous exercise. These adaptations are mainly described in male athletes. If the intense

Rev Argent Cardiol 2021;89:13-19. http://dx.doi.org/10.7775/rac.v89.i1.19245

Received: 11/30/2020 – *Accepted:* 01/18/2021

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physical exercise continues long enough, myocardial alterations may be observed. These include a drop in ejection fraction, decreased shortening fraction, increased end-diastolic volume, abnormal wall motion, altered myocardial fiber parameters, such as a drop in global longitudinal strain (GLS), and elevation of enzymes associated with myocardial injury. These changes in the absence of previous heart disease are attributed to exercise-induced cardiac fatigue (EICF), a relatively new term reported in the literature.

With the emerging trend of ultramarathon races, the presence of women participating in these events has increased in recent years (1). Despite the growing number of female participants in various high-performance competitions, information in this regard is still scarce. In a previous study we observed a lower presence of EICF in a reduced number of women. (2) The mechanisms involved in the presence or absence of physiological adaptations and EICF are not yet clear and are postulated as interindividual variability, which could be influenced by female gender. The purpose of this work was to analyze the differences observed according to gender in ultramarathon athletes before and after endurance exercise, in addition to conducting a review of the possible hypotheses that justify the differences found.

METHODS

The Cruce Mendoza race of the Alto running circuit is a race carried out in December of each year, starting from Villavicencio at a height of 1,800 meters above sea level (masl), with a temperature of 17 °C and a humidity of 12%. The race reaches its highest point at 25 km in Cruz de Paramillos at 3,200 masl with a temperature of -8 °C, progressing towards the Uspallata valley where temperature rises to 3 °C completing a 55 km course. It is a self-sufficiency race; therefore, the runner is responsible for his/her hydration, with hydration stations at 10 km, 25 km and 35 km.

Twenty-five athletes were invited to participate in the study and after obtaining an informed consent, the following self-referred data was collected: cardiovascular risk factors, cardiovascular history and usual medication. Average data on training type and intensity of the 6 months prior to the race were collected from sports watches (Garmin®, Tomtom®, Samsung®). The data collected were: resting HR (automatic average), training time in hours per week (average of the last 6 months), training load in monthly kilometers (monthly average of the last 6 months), average altitude of the workouts (workout average over the last 6 months), prevalent HR zone during workouts, prevalent HR zone during the race, and watch-estimated oxygen consumption (VO2) (Garmin® watches only). The HR zones were divided according to maximum percentage of HR in: very light or 1 (>50% and <60% of maximum HR), light or 2 (61%-70% of maximum HR), moderate or 3 (71%-80% of maximum HR), intense or 4 (81%-90% of maximum HR) and very intense or 5 (91%-100% of maximum HR). Other parameters were: time in minutes of the race for each athlete, position, weight before and after the race, baseline and immediately post-endurance exercise blood pressure and oxygen saturation by pulse oximetry.

Two echocardiographic cardiologists performed all studies with the same ultrasound machine (Vivid-i, General Electric Vingmed, Milwaukee, Wisconsin, USA). The images were stored and subsequently analyzed with the offline post-processing software. 2D left ventricular (LV) diameters were obtained from the left parasternal long-axis view and the right ventricular (RV) diameter from the apical 4-chamber plane at the level of the tricuspid annulus. Pulsed Doppler echocardiography was performed in the LV inflow tract at the level of the mitral free edge to determine ventricular filling pressures. A tissue Doppler (DTI) loop in the apical 4-chamber axis, as well as a pulsed tissue Doppler in the septal mitral annulus were stored to estimate the E/e' ratio. Right ventricular isovolumic relaxation time (RV IVRT) was measured [reference values close to 0 ms (3)] using on-line tissue Doppler, placing the pulsed Doppler cursor immediately above the tricuspid annulus on the RV free wall. Left atrial size was determined through the indexed atrial volume, performed in 4 and 2-chamber apical views. Right atrial size was estimated by apical 4-chamber view. End-diastolic and end-systolic volumes indexed to body surface area before and after endurance exercise were used to estimate preload and afterload parameters. Ventricular volume, ejection fraction (EF), cardiac output (CO) and GLS parameters were determined by means of automatic endomyocardial edge detection with the least possible intervention of the operator [automatic functional imaging (AFI)]. Ventricular torsion parameters, as well as RV free wall strain (RVFWS) were obtained by means of Q-analysis from the software determined for the equipment used (Echo-Pac, GE Medical version 202). Left atrial strain was calculated from the arithmetic mean of strain performed with Q-analysis in apical 4-chamber and 2-chamber axis views.

Twenty-three athletes agreed to participate in the laboratory sub-study. After signing the informed consent, 10 ml of blood were drawn immediately after the race. Since the Uspallata valley is located 120 km from the city of Mendoza and the first runners reached the finishing line around 5 am, samples were preserved in a freezer for later processing. The following analyses were performed: hemogram using a hematological Counter c19 plus, ionogram using indirect ISE technique, and CPK, CPK-MB and lactic acid with Architect c4000 auto analyzer. Troponins could not be processed due to the delay from extraction to sample processing.

To define EICF, we considered a decrease of more than 5% of LVGLS and a decrease of more than 5% of RVFWS for right heart fatigue. This parameter was considered in this way since we used the AFI system, which may present less than 5% variations between two studies.

Statistical analysis

A descriptive analysis was performed using conventional statistics, and groups were compared using Student's t test for independent samples. Quantitative variables were expressed as mean and standard deviation and qualitative variables as n and percentage. A p value <0.05 was considered as statistically significant.

Ethical considerations

All participants completed a sworn declaration of their personal data in which they granted consent for the anonymous publication of the study results.

RESULTS

Twenty-four of the athletes included in the study completed the 55 km race (only one woman abandoned in kilometer 35 due to muscle fatigue). Mean time in minutes from the end of the race until evaluation was 19±10 minutes.

Most participants were male athletes (n=19) with mean age of 42±12 years. Only 3 male participants presented cardiovascular risk factors (one hypertension and dyslipidemia, one hypertension and one smoking). Female participants were younger, with mean age of 38±4 years, but not significantly different from men (p=0.5), and no cardiovascular risk factors.

Mean time of sports training in men was 9±7 years (range 1 to 27 years), with a training load of 8.5±3.5 hours per week (range 5h to 20 h) and 175±53 km per month (range 93 km to 280 km) during the last 6 months. The training altitude ranged between a minimum of 110 meters above sea level (masl) and a maximum of 2500 masl (mean 1250±750 masl). Mean time of sports training in women was 7.8±5 years (range 2 to 15 years), with a training load of 11±3 hours per week (range 8 h to 15 h) during the last six months and 217±170 km per month (range 50 km to 540 km) during the last six months. The training altitude ranged between a minimum of 800 masl and a maximum of 2000 masl (mean 1350±388 masl), with no significant differences compared with men.

Twelve of the 19 male participants had watches designed for this sports practice (only 4 estimated maximum VO2). Mean resting HR was 57±7 beats per minute (bpm) (range 47 bpm to 80 bpm). The main HR zone during training was zone 4, same as in 80% of athletes during the race. Mean race time for this group was 425 min (311 min for the first place and 570 min for the last place).

Three of the 6 female participants had watches designed for this sports practice (only 2 estimated maximum VO2). Mean resting HR was 57±7 bpm (range 47 bpm to 70 bpm). The main HR zone during training was zone 3, same as in 100% of athletes during the race. Mean race time for this group was 424 min (356 min for the first place and 501 min for the last place) (Table 1).

Differences in baseline weight (p=0.001), height (p=0.001) and body surface area (p=0.001) were found between men and women. Although both HR at the end of the race as the HR zone during the race were lower in female athletes, these differences were not significant compared with men. (p=0.54 and p=0.13, respectively).

Baseline echocardiographic parameters showed that female competitors presented higher ejection fraction (p=0.03), lower indexed end-diastolic volume (p=0.01) and end-systolic volume (p=0.02), lower LV end-diastolic diameter (p=0.005) and a trend to greater GLS (p=0.08) (Table 1).

Echocardiographic parameters immediately after endurance exercise revealed that female competitors presented lower drop in ejection fraction (p=0.001), greater decrease in indexed end-diastolic volume (p=0.06) and end-systolic volume (p=0.003), lower CO (p=0.02), lower increase in end-diastolic LV diameter (p=0.03), lower RV dilation (p=0.01) and right atrial dilation (p=0.007), lower RV IVRT (though not significan, p=0.3), greater GLS (p=0.016) and greater left atrial strain (p<0.005). This correlates with lower incidence of EICF in female athletes (EICF for the right ventricle, p=0.03 and for the left ventricle, p <0.001).

Laboratory test data showed lower lactic acid levels in women and lower CPK elevation, though not statistically different compared with men (p=0.3 and p=0.6, respectively) (Table 2).

DISCUSSION

There is limited bibliographic information on EICF, and even more when considering women. Therefore, the influence of sex on the physiological adaptations to competitive exercise-induced stress is merely hypothetical.

Men and women presented similar training characteristics, both in hours and kilometers, besides completing the competition in similar times.. However, we observed hearts with less baseline physiological adaptation, though with similar HR at rest and lower during exercise. Concomitantly with a previously published work, (2) female competitors presented lower incidence of EICF, in addition to lower lactic acid levels after the competition and slightly lower CPK-estimated muscle injury.

Some of these variations might be explained by the intensity of the competition. If we consider the myocardial ischemic/stunning theory of cardiac fatigue, assuming that the drop in GLS is due to damaged endomyocardial fibers, the most sensitive to ischemia, which is secondary to the decrease of diastolic perfusion time during long periods of competition, it can be observed that female athletes performed the competition at lower HR zones than men. This correlates with greater diastolic perfusion for women during the competition and is also reflected in the lower concentration of waste products, such as lactic acid.

But not all men presented EICF and not all women are protected from it, so, even though there is a sex-associated influence, other parameters may also collaborate in the protection against EICF.

An interesting theory is the one postulated by Sanz de la Garza's group and other authors (8, 9) which show the capacity of some athletes to recruit anatomical arteriovenous shunts or dilate the pulmonary capillaries during exercise, as demonstrated through the passage of contrast (agitated saline solution) to the left chambers without the presence of intracardiac shunt, immediately after strenuous exercise. This capacity is an indicator of pulmonary capillary reserve and is associated with lower increase of pulmonary arterial pressure and less repercussion in wall stress on the right ventricle. (9) In our work, this response

Table 1. Population characteristics and baseline Doppler echocardiography

Parameter	Sex	Mean	SD	P (2-tailed)
Age (years)	F	38	±4	0.547
	M	42	±12	
Weight (kg)	F	56.50	3.728	0.001
	M	76.42	12.834	
Height (cm)	F	163.00	5.514	0.001
	M	174.74	7.023	
Body surface area (m2)	F	1.5717	0.06242	<0.001
	M	1.8842	0.18216	
HR (beats per minute)	F	57.67	7.501	0.938
	M	57.95	7.553	
Years of previous training	F	7.80	5.119	0.637
	M	9.29	7.069	
Training load per week (hours)	F	11.17	3.061	0.133
	M	8.58	3.639	
Training load per month (km)	F	217.67	170.976	0.317
	M	172.56	52.165	
Training altitude (masl)	F	1350.00	388.587	0.668
	M	1235.89	598.212	
HR zone during training	F	3.5000	0.70711	0.123
	M	4.0000	0.44721	
HR zone during the race	F	3.4000	0.54772	0.131
	M	4.0000	0.63246	
Watch-estimated O2 consumption	F	32.33	28.042	0.267
	M	49.75	5.620	
Race duration (minutes)	F	424.0	62.382	0.953
	M	425.84	61.853	
HR after race	F	83.17	5.345	0.541
	M	85.63	9.160	
EF (%)	F	62.67	1.633	0.031
	M	59.88	4.106	
LVEDV/m2	F	49.8333	5.07609	0.007
	M	58.8438	7.97855	
LVESV/m2	F	19.7500	2.18518	0.006
	M	24.0375	4.09176	
CO (l/min)	F	3.2000	0.77201	0.084
	M	3.9824	0.94818	
LVDD (mm)	F	44.5000	3.20936	0.005
	M	49.3529	3.29661	
LAVI (ml/m2)	F	35.8833	8.57681	0.453
	M	33.4471	5.99928	
RVDD (mm)	F	35.5000	3.33167	0.234
	M	38.2353	5.05630	
RAA (cm2)	F	15.2000	15.2000	0.006
	M	18.5059	18.5059	
TAPSE (mm)	F	27.333	2.9439	0.738
	M	27.706	2.0846	
LVS (cm/s)	F	9.0000	2.00000	0.292
	M	10.5294	3.22331	
PASP (mmHg)	F	26.2500	5.73730	0.513
	M	24.0000	5.61743	
E/A	F	1.0000	0.00000	0.402
	M	1.1176	0.33211	

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Parameter	Sex	Mean	SD	P (2-tailed)
e´ (cm/s)	F	15.8333	4.02078	0.040
	M	12.4706	2.93934	
E/e´	F	5.6840	1.09192	0.658
	M	6.1529	2.22461	
Twist (°)	F	9.9400	1.70529	0.825
	M	9.5727	3.41968	
RVFWS (%)	F	27.3333	2.86403	0.950
	M	27.1429	7.03384	
LAS (%)	F	27.7500	4.78714	0.575
	M	29.2000	4.49177	
GLS (%)	F	21.2167	0.82321	0.018
	M	19.7353	1.91146	

HR: Heart rate, EF: Ejection fraction, LVEDV/m2: Left ventricular end-diastolic volume indexed to body surface area, LVESV/m2: Left ventricular end-systolic volume indexed to body surface area, CO: Cardiac output, LVDD: Left ventricular diastolic diameter, LAVI: Left atrial volume index, RVDD: Right ventricular diastolic diameter, RAA: Right atrial area, TAPSE: Tricuspid annular plane systolic excursion, LVS: Left ventricular mitral annulus S wave by tissue Doppler, PASP: Pulmonary artery systolic pressure, E/A: Transmitral relaxation pattern, e': mitral annulus tissue Doppler e´ wave, E/e': E/e' ratio, Twist: ventricular torsion, RVFWS: Right ventricular free wall strain, LAS: Left atrial strain, GLS: Global longitudinal strain.

Table 2. Post endurance exercise Doppler echocardiography and laboratory results

Parameter	Sex	Mean	SD	P (2-tailed)
EF (%)	F	62.6667	2.50333	0.001
	M	57.6316	3.04066	
LVEDV/m2 (mL/m2)	F	45.1667	4.35507	0.018
	M	51.9474	8.20890	
LVESV/m2 (mL/m2)	F	17.0000	1.78885	0.003
	M	22.7895	4.17105	
CO (L/min)	F	3.4000	0.72938	0.026
	M	4.1842	0.69463	
LVDD (mm)	F	43.6667	3.26599	0.036
	M	47.0526	3.23992	
LAVI (mL/m2)	F	26.3333	7.20185	0.437
	M	28.2632	4.50730	
RVDD (mm)	F	33.1667	4.16733	0.003
	M	41.2632	6.69861	
RAA (cm2)	F	14.4000	2.19089	0.007
	M	18.8632	3.10559	
RVS (cm/s)	F	13.3333	2.73252	0.972
	M	13.3684	1.86221	
RV IVRT (ms)	F	84.6667	33.12200	0.347
	M	100.4211	36.46965	
TAPSE (mm)	F	22.6667	3.88158	0.322
	M	24.6316	4.21914	
LVS´(cm/s)	F	10.3333	1.50555	0.495
	M	11.2632	3.14187	
PASP (mmHg)	F	22.0000	2.89828	0.363
	M	23.8235	4.44741	
E/A	F	1.0000	0.00000	0.086
	M	1.3684	0.49559	
e´ (cm/s)	F	16.3333	2.87518	0.162
	M	14.1053	3.39763	
E/e´	F	4.0000	1.00000	0.475
	M	4.5368	1.20460	

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Parameter	Sex	Mean	SD	P (2-tailed)
Twist (°)	F	9.6667	2.87518	0.873
	M	9.4106	3.43796	
RVFWS (%)	F	25.0000	3.39116	0.564
	M	23.2938	6.14008	
LAS (%)	F	42.3333	10.48173	0.000
	M	27.5278	6.27195	
GLS (%)	F	21.7333	2.73252	0.016
	M	18.7526	2.35381	
Hematocrit (%)	F	39.0000	3.34664	0.065
	M	41.4706	2.42687	
Na (mEq/L)	F	134.0000	1.78885	0.017
	M	136.7059	2.31205	
K (mEq/L)	F	5.2167	0.44008	0.951
	M	5.2059	0.33442	
Cl (mEq/L)	F	99.8333	2.31661	0.020
	M	102.5882	2.29289	
CPK (U/L)	F	525.8333	491.89406	0.500
	M	651.5882	345.81354	
CPK-MB (U/L)	F	56.3333	34.33754	0.698
	M	51.5882	21.81186	
Lactic acid (mmol/L)	F	2.6333	1.25804	0.018
	M	4.3706	1.34013	

EF: Ejection fraction, LVEDV/m2: Left ventricular end-diastolic volume indexed to body surface area, LVESV/m2: Left ventricular end-systolic volume indexed to body surface area, CO: Cardiac output, LVDD: Left ventricular diastolic diameter, LAVI: Left atrial volume index, RVDD: Right ventricular diastolic diameter. RAA: Right atrial area, RVS: Right ventricular tricuspid S wave by tissue Doppler, RV IVRT: Right ventricular isovolumic relaxation time, TAPSE: Tricuspid annular plane systolic excursion, LVS: Left ventricular mitral annulus S wave by tissue Doppler, PASP: Pulmonary artery systolic pressure, E/A: Transmitral relaxation pattern, e': mitral annulus tissue Doppler e´ wave, E/e': E/e' ratio, Twist: ventricular torsion, RVFWS: Right ventricular free wall strain, LAS: Left atrial strain, GLS: Global longitudinal strain, Na: Sodium (reference values 135 mEq/L to 145 mEq/L), K: potassium (reference values 3.5 mEq/L to 5 mEq/L), Cl: Chloride (reference values 95 mEq/L to 110 mEq/L), CPK: Creatine phosphokinase (reference values below 130 U/L in men and 110 U/L in women), CPK-MB: MB fraction of CPK (reference values below 25 U/L in men and women), lactic acid (reference values below 1.9 mmol/L)

correlates with the lower increase of IVRT observed in women, an indicator of lower pulmonary vascular resistance. Although there is scarce information, women present greater presence of arteriovenous shunts, which explains a less affected diastolic RVFWS and hence lower right EICF.

Another parameter that can collaborate with lower EICF is arterial compliance, which would improve peripheral vascular resistance, reducing the load imposed on both ventricles and increasing peripheral oxygen extraction. This compliance, which has been more frequently observed in women after exercise, (10) may be influenced by the vasodilator effect of estrogen (11) and age, since it inversely declines proportionately with age. The lower presence of EICF, as well as the lower production of lactic acid in female competitors, could be influenced by sex and lower age compared with male competitors.

All the postulated hypotheses to explain the differences found in the physiological adaptations and the response of the heart immediately after endurance exercise, as well as the presence of lower EICF in women, have not yet sufficient bibliographic support, but the theories are very attractive. It is probable that hormone differences are responsible of many of the observed dissimilarities between men and women.

As we had a low number of female competitors, the study was made to postulate hypotheses rather than confirm them.

CONCLUSIONS

Ultramarathon female competitors show less EICF, in addition to different parameters of physiological adaptation to exercise stress, such as lower HR during the competition, reduced elevation of pulmonary vascular resistance during endurance exercise and lower lactic acid levels compared with male competitors.

Conflicts of interest

None declared.

(See authors' conflicts of interest forms on the website/Supplementary material)

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