ISSN 1590-8844
International Journal of Mechanics and Control, Vol. 26, No. 01, 2025
https://doi.org/10.69076/jomac.2025.0017

CARDIOVASCULAR AND METABOLIC ENGAGEMENT AFTER AN ENDURANCE RACE IN PILOTS DRIVING MOTORBOATS ELECTRICALLY POWERED BY GREEN ENERGY

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ABSTRACT

During the Sardinia Innovative Boat Week, held in Olbia, Italy, in September 2024, several teams of students and university researchers, competed with self-built prototypes in a motorboats endurance race, i.e. the a Ton's Race, lasting 4 hours and dedicated to electrically powered boats. Just before and after the race, 5 pilots: 4 males and 1 female ageing 28.8 ± 17.7 years, were engaged for several non-invasive anthropometric, psychometric, metabolic and cardiovascular tests (these latter by an Authors self-built electrical impedance cardiograph) through which was found post-race falling in the body mass (-0.6 kg) with statistically significant reduction in ventricle preload (-21%) and heart rate (-13%), and increases in ventricle ejection velocity (23%), after load (12%), heart mechanical efficiency (23%). Experimental results outline for the first time a biomechanical functional model of the main adaptations of the organs recruited in this new and green motor boats sports activity.

Keywords: motor boat races, electrical powered engines, electrical impedance cardiography, bioenergetics

1 INTRODUCTION

During the Sardinia Innovative Boat Week held in Olbia, Italy, in September 2024, several teams of students and university researchers, coming from various European countries, met in this pleasant seaside location with the common goal of concentrating scientific skills, technologies and human resources, giving life to a competitive event: a race dedicated to electric boats.

This sport-technological event was typically characterized by its efficiency for which electric mobility is proposed as one of the best systems to achieve a substantial balance.

This event held in Olbia, linking the competitions between prototypes of motor boats, built by young engineers from prestigious universities with a strong push towards increasingly stringent objectives aimed at reducing the environmental impact of the transport system, paid a growing focus on greater energy to meet the pressing need to implement the ecological transition also at sea, has certainly proved to be a winning idea.

In fact, conceived by laboratories and spin-offs of international academic origin and mostly piloted by researchers and university students, these revolutionary boats were the expression of a vision of the future, in which environmental protection and innovation must be inseparable.

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In addition to all of what above, it should not be overlooked that sport's performances at sea with these characteristics certainly require a high level of physical and mental efforts from the pilots, also in considering what observed in previous experiments concerning of staying at sea for several hours on small boats. In fact, in a previous study [1] it has been shown that in sailors exposed 2.5 hours in the sea with a wind speed of 24 $km\ h^{-1}$ and an air temperature of 7 *°C*, there was a significant reduction of body mass, mainly caused by water loss, together with a fall in the blood electrolytes concentrations.

Furthermore, previous anxiety-related conditions, which these motorboat pilots may have been interested, could have affected neurovegetative homeostasis during the race with performance effects mainly of cardiometabolic nature. In this sense, possible increases in cortisol release when driving boats powered by fossil fuel engines should not be overlooked, as this type of engine produces loud noises and strong mechanical vibrations, both of which are known to give rise to increases in the blood concentration of this hormone with cardiovascular excitatory activity [2, 3, 4].

Taking advantage of this exceptional event where a large number of pilots of electric motor boats find themselves all together competing in endurance nautical performances, the goal of better knowing which body systems adjustments occur in athletes dedicate to performing long lasting motor boat races in the sea, electrically powered, is the goal to be achieved here. In this aim, in a group of pilots voluntarily engaged the after race changes in anthropometric, hemodynamic and metabolic variables were compared with those occurred before race.

2 METHODS

2.1 SUBJECTS

Boat's pilots engaged in this study were 5 of which 4 males and one female, ageing 28.8 ± 17.7 years (lower age: 16 years, higher age: 60 years); their height and body mass were respectively 172 ± 3.5 cm and 67.1 ± 5.9 kg. Just before experimental engagement, for each chosen pilot a team's physician proceeded to an anamnestic interview from which was ascertained his suitability for this research. They were then informed about the experimental procedure and all declared their informed consent.

2.2 THE BOATS

All engaged pilots competed in the Uniclass Category, of which a boat is shown in figure 1, being catamaran hulls with a maximum weight of 250 kg of which 90 kg including pilot size. The hull dimensions were: length 5.5 m, width 2.5 m with 40 cm over water. The organization of the motorboat event provided innovative ready-to-use hulls, i.e. the so called Uniclass Category, for the races upon request. These catamarans are the result of an innovative design and boat construction technology characterized by standards of lightness and strength.

They are made with an owned combination of carbon fibres and hemp that ensures a robust structure and lightweight in vessels. All teams were required to install their propulsion units and control systems on these hulls and competing using only clean energy sources such as electrical batteries. The electrical motors developed by the various teams were powered with voltages ranging between 48 V and 96 V.

Figure 1 Typical boat Uniclass prepared by one of the crews participating in the Olbia's competition with its pilot positioned in the cockpit while preparing to start an endurance race. A rechargeable battery bank is positioned behind the cockpit.

2.3 EXPERIMENTAL PROTOCOL

All the 5 chosen pilots were tested just before (T1) and after (T2) being they engaged in a Ton's Race, lasting 4 hours, travelling in a circular motion several times in the stretch of sea in front of the port of Olbia, in Italy.

2.3.1 Clinical and functional evaluations

By a portable electronic scale (INN-117, Innoliving Ltd, Italy) and a common wall tape measure, in both T1 and T2 tests were recorded from each subject, while standing barefoot, the height in cm and the body mass (BM) in *kg* [5].

Furthermore, after having carried out the anthropometric measurements and while the pilots were seated, the following clinical-functional measurements were also not invasively made on them:

- systolic (SABP) and diastolic (DABP) arterial blood pressures measurement, in *Torr*, using a commercial automatic cuff sphygmomanometer (Omron m3, Netherlands), from both which the mean arterial blood pressure was also calculated as: MABP = DAP + 1/3 (SAP + DAP) [6, 7];
- peak of the expiratory flow (PEF) production, in $l\ min^{-1}$, using a special graduated cylinder inserted through mouth in which the subject produced a maximum air outflow (Mini-Wright, Clement-Carke Int. UK) [8];
- maximum force expression during the handgrip maneuver (HGM), measured in *kg*, carried out with the dominant hand, using a dedicated, commercial device (Gripx, Vatmaster Consulting, Germany) [9];
- urine specific density (SDU) measured by means of reactive strips (Combi Screen, Germany) [10];
- body temperature (BT), measured in *°C*, by an electronic thermometer for tympanic assessments (Gima, Italy) [11].

2.3.2 Cardiodynamic evaluations

By means of a self-built portable electrical impedance cardiograph (EIC), already validated and tested [12, 13, 14], which was supplied by an autonomous power bank, both beat-to-beat thoracic electrical impedance (Zt) and electrocardiogram (ECG) tracks were assessed from each engaged subject. Their thorax was connected to the EIC through 4 couples of disposable electrodes positioned within the ideal truncated cone having the lower base lying on the plane of the xiphoid process and the upper base on the plane of the roots of the neck muscles [15]. The two external pairs of electrodes injected into the thorax an alternating mono frequency (65 *KHz* which eliminates the capacitive reactance [16]) current (It) of constant intensity (1 *mA*), while the 5 cm more internal pairs detected the resulting drop in the applied electrical potential difference (ΔVt) [17]. By applying the Ohm's law, the software implemented in the EIC returned the corresponding Zt as:

$$Zt = \Delta Vt : It \tag{1}$$

By utilizing a free LabChart reader (ADInstruments USA) for data acquisition and data analysis, from the instrumental tracks of the Zt, its first derivative Zt/dt and ECG, the following cardiodynamic variables were beat-to-beat acquired as shown in figure 2:

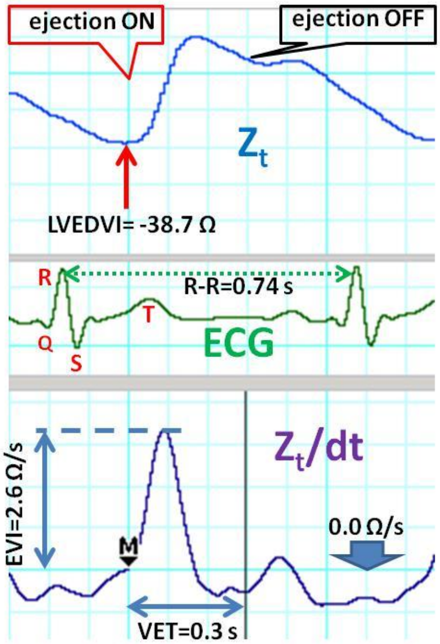

Figure 2 Within a typical heart beat of a tested pilot, from top to bottom, tracks show changes in thoracic electrical bioimpedance (Zt), electrocardiogram (ECG) and mathematical first derivative of the thoracic electrical bioimpedance (Zt/dt). LVEDVI: index of the inverse left ventricle end diastolic volume, R-R: between ECG's R waves time interval, EVI: left ventricle ejection velocity peak index, VET: left ventricle ejection time. M: graphic marker indicating the precise time in which started the left ventricle ejection, Q-R-S: left ventricle ECG depolarizing waves, T: left ventricle repolarising wave.

- the index of the inverse value of the left ventricle end diastolic volume (LVEDVI), represented in the impedance track of figure 2 as the minimum value assumed by Zt, in Ω^{-1}, since it has been found that this Zt value inversely correlates with the left ventricle pre-load [18];
- left ventricle index of peak ejection velocity (EVI), measured in $\Omega\ s^{-1}$ as the maximum amplitude in the Zt/dt track (third track from top in figure 2) since it has been found that this electrical variable overlaps the track of blood flow velocity in the aorta artery, assessed with the Doppler technique and measured in $m\ s^{-1}$ [19];
- left ventricle ejection time (VET), measured in *s* in the Zt/dt track as the time interval between the start of the EVI and its after-peak mathematical minimum value since it has been found that these two time points respectively correspond to the first and second sound of the cardiac phonocardiogram or the opening and closing in the aortic valve [20].

Since it is known that the ejection fraction of the ventricle volume during the systole depends on: the ventricle hydraulic volume (HVV), its pre-load, its ejection velocity peak and the corresponding ejection time, so the following equation could be proposed to evaluate the left ventricle stroke volume (SV) by substituting measurable impedance derived variables to the hydraulic ones as:

$$SV = HVV \text{ x } LVEDVI \text{ x } EVI \text{ x } VET \tag{2}$$

Equation (2) allows to calculating the beat-to-beat SV provided that the HVV must be known. This limitation has been overcome by the experimental observation that this volume is comparable to that of the volume of the thoracic electrically participating tissues (VEPT) expressed in cm^3 [21], and that the latter can be obtained from an experimentally acquired nomogram, through the body weight, height and the gender of the subject concerned [17]. So, the transfer equation from electrical to hemodynamic variables for the beat-to-beat measurement of SV can be quantitatively formulated as follows [22]:

$$\begin{array}{l} SV = (VEPT) \text{ x } (LVEDVI) \text{ x } (EVI) \text{ x } (VET) = \\ \quad (\mathrm{cm}^3) \text{ x } (\Omega^{-1}) \text{ x } (\Omega\ \mathrm{s}^{-1}) \text{ x } (\mathrm{s}) = \mathrm{cm}^3 \end{array} \tag{3}$$

Equation (3) had been previously validate by comparing SV obtained in this way with that detected with other standardized methods [23]. Moreover, it has been utilized this non invasive technique also in acquiring cardiodynamic variables in racing car pilots [24]. Both during the T1 and T2 tests, while measuring the arterial blood pressures, each pilot kept sitting 2 minutes during which the beat-to-beat Zt and ECG tracks were assessed, from which, subsequently, 10 heartbeats were analyzed in temporal succession starting from the beginning of the second minute of acquisition. This time delay was set to distance the period of acquisition of the haemodynamic variables from that during which the measurement of arterial blood pressures was carried out in such a way of avoiding mental troubles influences in the analyzed heart beats.

Moreover, from the figure 2 (second track from top) it can be obtained the value of the heart rate per minute (HR) concerning a given heart beat as dividing 60 to the measured R-R time interval. For instance, in the heart rate analyzed in figure 2, by dividing 60 to 0.74 was obtained an HR of 81 beats per minute.

Additional hemodynamic variables that were obtained from data collected in figure 2 are those following:

- cardiac output per minute (CO) as the product SV x HR, measured in $l\ min^{-1}$;
- total peripheral vascular resistance index (PVR) obtained by dividing the (MABP) at rest to the CO, measured in $Torr\ l^{-1}\ min^{-1}$;
- rate-pressure product (RPP) obtained by multiplying the SABP by the HR, measured in $Torr\ beats^{-1}\ min^{-1}$ and considered as an indirect index of myocardial oxygen consumption or heart's energy cost [25];
- mechanical work index of the left ventricle (LVMW) as the product of MABP and SV, measured as *Torr ml* [26];
- left ventricle mechanical efficiency index (LVME) obtained as the ratio between LVMW and RPP and measured as $ml\ beats\ min^{-1}$ [26].

Furthermore, EVI was chosen here as a good index of myocardial contractility.

2.3.3 Psychometric evaluations

In the aim of verify possible conditioning of the hemodynamic variables of interest by previous states of anxiety, at the time of their engagement the pilots were administered a specific questionnaire: the Generalized Anxiety Disorder 7-item (GAD-7) [27], shown in table I, in which a total score for the chosen seven items ranges from 0 to 21. In the GAD-7 a score from 0 to 4 implies minimal anxiety, from 5 to 9 indicates mild anxiety, from 10 to 14 indicates moderate anxiety while from 15 to 21implies a condition of severe anxiety.

3 RESULTS

Table IIa shows changes in BM occurring in each tested pilot when he landed after 4 hours competing in the motorboat Ton's Race (T2), compared to the same measurements assessed before the race (T1). It can be shown that the after race BM was reduced on average of 600 *g* or quasi 1%.

However, applying the statistic Student's *t* test for paired data between T1 and T2 values and considering a P<0.05 as statistically significant (MedCalc statistical package, Belgium), despite an important loss of the average value in the BM, this anthropometric variable did not reached an after-race statistically significant difference (P=0.867). Moreover, this table shows that, after race, MABP increased on average of about 8 *Torr* or quasi 10% respect the value assesses before race. The table also shows that the measured tympanic BT never fell under 36°C while still maintaining values always below 37°C.

Table I - GAD-7 Anxiety questionnaire

Over the last two weeks, how often have you been bothered by the following problems?	Not at all	Several days	More than half the days	Nearly every day
1. Feeling nervous, anxious, or on edge	0	1	2	3
2. Not being able to stop or control worrying	0	1	2	3
3. Worrying too much about different things	0	1	2	3
4. Trouble relaxing	0	1	2	3
5. Being so restless that it is hard to sit still	0	1	2	3
6. Becoming easily annoyed or irritable	0	1	2	3
7. Feeling afraid, as if something awful might happen	0	1	2	3

Table IIa - Subjects clinical and functional variables before (T1) and after (T2) race

Sub.	BM (*kg*)		MABP (*Torr*)		BT (*°C*)	
	T1	T2	T1	T2	T1	T2
(A)	70.3	68.9	78.3	88.7	36.1	36.5
(B)	61.7	60.8	91	93.3	36.1	36.4
(C)	70.2	68.6	90	90	36.9	36.1
(D*)	60	61.4	83.3	78.7	36.4	36.7
(E)	73.3	72.6	84	117	36.2	36.1
M.	*67.1*	*66.5*	*85.3*	*93.5*	*36.3*	*36.4*
±SD	*5.9*	*5.1*	*5.2*	*14.2*	*0.34*	*0.26*
Δ		*-0.6*		*8.2*		*0.1*

Sub.: subjects; BM: body mass; MABP: mean arterial blood pressure; BT: body temperature; M.: mean; ±SD: standard deviation; Δ: T1-T2; *: woman

Table IIb - Subjects clinical and functional variables before (T1) and after (T2) race

Sub.	SDU_{urine} (*Abs. Units*)		HGM (*kg*)		PEF ($l\ min^{-1}$)	
	T1	T2	T1	T2	T1	T2
(A)	1025	1010	50.5	45.4	640	740
(B)	1025	1005	56.8	53.3	550	570
(C)	1020	1010	42.8	43.2	570	580
(D*)	1005	1010	39	35.7	250	390
(E)	1015	1010	51.2	46.5	610	630
M	*1018*	*1009*	*48.1*	*44.8*	*524*	*582*
±SD	*8.4*	*2.2*	*7.1*	*6.3*	*157*	*127*
Δ		*-9*		*-3.3*		*58*

Sub.: subjects; SDU: specific density units; HGM: handgrip maneuver; PEF: peak of expiratory flow; (Abs. Units): Absolute Units; M: mean; ±SD: standard deviation; Δ: T2-T1; *: woman

Table III - GAD-7 questionnaire results

Sub.	Not at All (0)	Several Days (1)	More than half The days (2)	Nearly every Day (3)	Total
(A)	2	5			5[b]
(B)	3	2	2		6[b]
(C)	4	3			3[a]
(D*)	3	3	1		5[b]
(E)	1	1	3	2	13[c]

Sub.: subjects; [a]minimal anxiety; [b]mild anxiety; [c]moderate anxiety; *: woman

However, neither MABP nor BT averaged values differences between before and after race reached the statistical significance. Table IIb shows that while the T2 averaged value of PEF increased 58 *l min*$^{-1}$ or +11% with respect to the T1, on the contrary, both SDU and HGM reduced their averaged values after performing the race. In fact, the former variable was lowered of 9 *Units*, i.e. quasi 1%, and the second one fell on average of more than 3 kg or almost – 7% the pre race value. However, in the variables shown in this table, statistical comparisons among T1 and T2 conditions by the Student's *t* test appeared as significant only concerning the after race reduction in the SDU (P=0.0491). In table III the anxiety scores, i.e. the GAD-7, reached by each pilot over the last two weeks before the green motor boating races, are reported. In the pre-race period only one of they came from a minimal level of anxiety, three had experienced mild anxiety while the latter was as moderately anxious. Concerning hemodynamic data acquired when assessing, beat-by beat, 2 minutes of EIC tracks from each subject both at T1 and T2 experimental conditions , it has been chosen to analyse, by means of the free LabChart software, the first 10 heart beats which followed one another immediately after the start of the second minute recording. In the aim of compare for each chosen haemodinamic variable data from T1 versus T2 conditions to establish possible differences statistically significant, for each variable were pooled the data of all the values acquired from each subject in each of the two experimental conditions therefore, constituting, for a given variable, two groups of data each of 50 values in order to compare them statistically. Firstly, it has been tested the degree of normality of each data distribution using the D'Agostino-Pearson test for normal distribution [28], establishing in this way that almost all of the data distributions rejected the parametric condition.

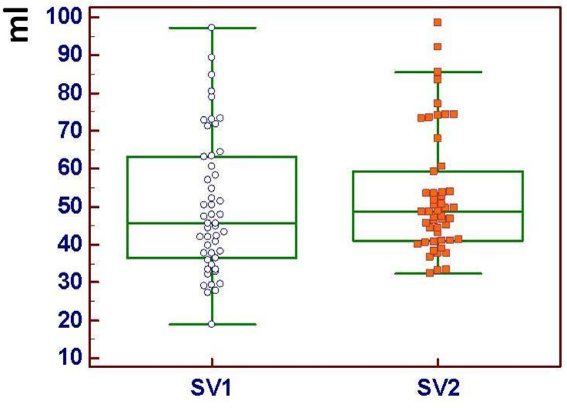

Figure 3 Box and whiskers representation shows left ventricle stroke volume distribution among all tested subjects respectively before (SV1) and after (SV2) boat's performances. Fifty heart beats were considered in both former (empty blue circles) and second (full orange squares) cardiovascular tests. The orange squares outside the graphs are outlier values.

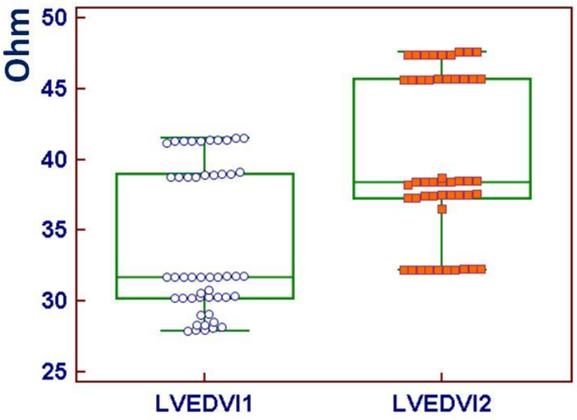

Figure 4 Box and whiskers representation shows inverse left ventricle end diastolic volume index distribution among all tested subjects respectively before (LVEVI1) and after (LVEVI2) boat's performances. Fifty heart beats were considered in both former (empty blue circles) and second (full orange squares) cardiovascular tests.

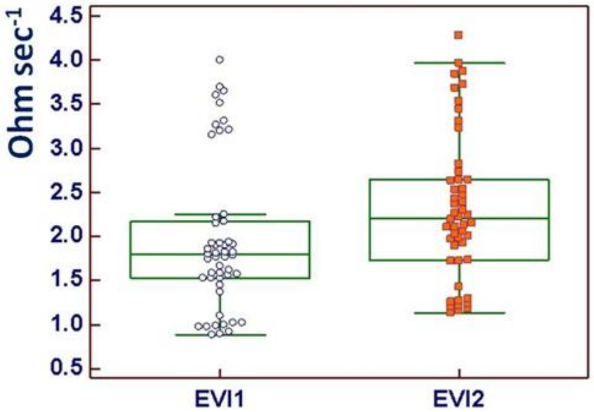

Figure 5 Box and whiskers representation shows left ventricle peak ejection velocity index distribution among all tested subjects respectively before (EVI1) and after (EVI2) boat's performances. Fifty heart beats were considered in both former (empty blue circles) and second (full orange squares) cardiovascular tests. The orange squares outside the graphs are outlier values.

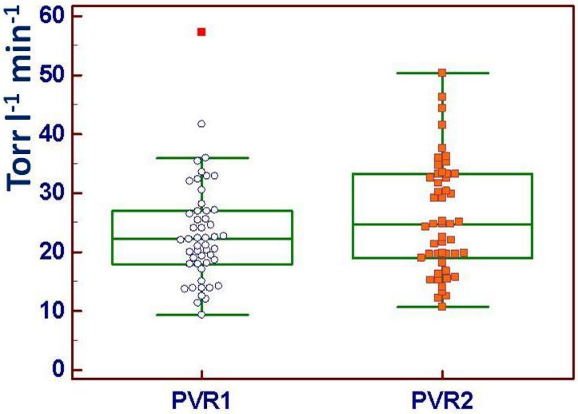

Figure 6 Box and whiskers representation shows left ventricle total peripheral vascular resistance index distribution among all tested subjects respectively before (PVR1) and after (PVR2) boat's performances. Fifty heart beats were considered in both former (empty blue circles) and second (full orange squares) cardiovascular tests. The orange squares outside the graphs are outlier values.

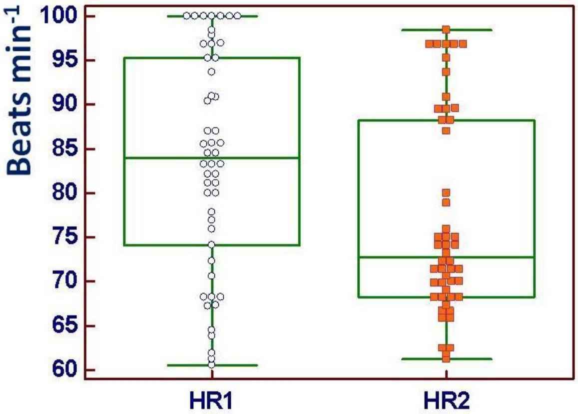

Figure 7 Box and whiskers representation show heart rate per minute distribution among all tested subjects respectively before (HR1) and after (HR2) boat's performances. Fifty heart beats were considered in the former (empty blue circles) and second (full orange squares) cardiovascular tests.

Whereby, for the comparison between the data collected in T1 and T2 it has been chosen to use the non-parametric Wilcoxon test for paired data [28]. So, data were graphically represented by the box and whisker plot method which displays a statistical summary of a variable in terms of median, quartiles and extreme values [29, 30]. Graphs in figures from 3 to 9 concern the two box and whisker plots for each data distribution assessed in T1 and T2, respectively for: SV, LVEDVI, EVI, PVR, HR, CO, LVME. About the SV, from graphs in figure 3 it can be easily shown that despite the interquartile box values of SV2 (from 42.0 to 59.4 *ml*) entirely falls within that of V1 (36.5 to 63.2 *ml*), however the VS2 median (48.7 *ml*) enhanced the VS1 one (45.6 *ml*) of 6.8%. Nevertheless, the statistical significance for this comparison was not reached, even if only by a little.

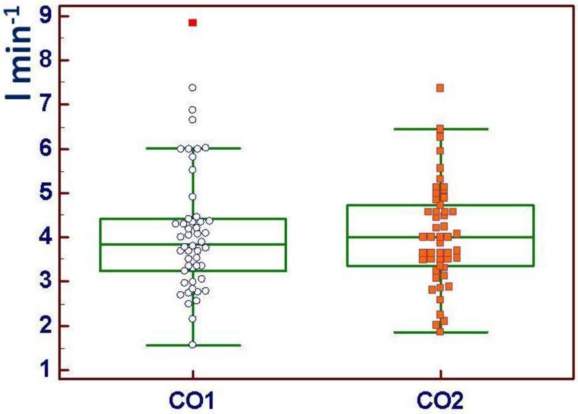

Figure 8 Box and whiskers representation show left ventricle cardiac output per minute distribution among all tested subjects respectively before (CO1) and after (CO2) boat's performances. Fifty heart beats were considered in the former (empty blue circles) and second (full orange squares) cardiovascular tests. The orange squares outside the graphs are outlier values.

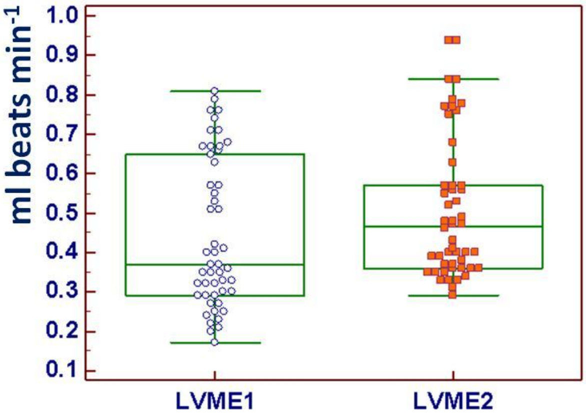

Figure 9 Box and whiskers representation show left ventricle mechanical efficiency index distribution among all tested subjects respectively before (LVME1) and after (LVME2) boat's performances. Fifty heart beats were considered in both former (empty blue circles) and second (full orange squares) cardiovascular tests. The orange squares outside the graphs are outlier values.

Graphs in figure 4 show the LVEDVI distribution assessed during both T1 and T2 tests. It can be shown that LVEDVI distribution in T2 was positioned much higher than in T1. In fact, the interquartile range of this variable assessed after race shows values from 37.3 to 45.7 *Ω* while before race these were from 30.2 to 39.0 *Ω*. Moreover, the LVEDVI2 median (38.4 *Ω*) was about 21% higher than in the LVEDVI1 (31.7 *Ω*) distribution, and for this reason this difference was statistically significant ($P<0.0001$). As previously specified in the methods at paragraph 2.3.2, the variations of the end-diastolic ventricular volume must be interpreted as reciprocal values with respect to those shown in the figure which represent the variations of the thoracic bioimpedance. Therefore, the data in this figure agree with a significant decrease in the ventricular preload which occurred after the race. Now considering the left ventricle ejection velocity peak (EVI), its data distribution in T2 versus T1 (figure 5) shows that the T2 interquartile range was noticeably higher (from 1.73 to 2.65 $\Omega\ s^{-1}$) than in T1 (from 1.53 to 2.17 $\Omega\ s^{-1}$) and the median after race (2.21 $\Omega\ s^{-1}$) was +23.5% than that before race (1.79 $\Omega\ s^{-1}$), so the difference among these two distribution was statistically significant ($P<0.0001$). The total peripheral vascular resistance index (PVR in figure 6), assessed during the T2 showed an interquartile range (from 19.0 to 33.2 $Torr\ l^{-1}\ min^{-1}$) that was a little bit higher than during T1 (from 18.0 to 26.9 $Torr^{-1}\ l^{-1}\ min^{-1}$). However, even if the post-race median (24.7 $Torr\ l^{-1}\ min^{-1}$) of the PVR was higher than 12% of in the pre-race one (22.1 $Torr\ l^{-1}\ min^{-1}$), this difference had a $P=0.05$ or borderline for statistical significance. Heart rate per minute (HR) distribution assessed during the two experimental conditions is shown in figure 7.

Interquartile ranges of this variable show a partial superimposition when comparing T1 (from 74.2 to 95.2 $beats\ min^{-1}$) versus T2 (from 68.2 to 88.2 $beats\ min^{-1}$) data distribution, and the median in T2 (72.7 beats min^{-1}) was 13.2% lower than the one in T1 (83.8 $beats\ min^{-1}$) for which its distribution in T2 was significantly lower than in T1 ($P=0.008$). Cardiac output per minute (CO) shows in figure 8 that interquartiles of both T1 (from 3.24 to 4.42 $l\ min^{-1}$) and T2 (from 3.35 to 4.74 $l\ min^{-1}$) data were practically overlapped as well as their medians: respectively of 3.84 and 4.00 l min^{-1}. In fact, this comparison did not reach statistical significance ($P=0.685$). In figure 9 are shown box and whisker plots for data distributions concerning the left ventricle mechanical efficiency index before (LVME1) and after the race (LVME2). Despite interquartile range of T2 (from 0.36 to 0.57 $ml\ beats\ min^{-1}$) was entirely contained within the one of T1 (from 0.29 to 0.65 $ml\ beats\ min^{-1}$), the T2's median value (0.47 $ml\ beats\ min^{-1}$) was 27% higher in comparison to that of the T1 (0.37 $ml\ beats\ min^{-1}$), and this post-race higher median value than before one was statistically significant ($P=0.0026$).

5 DISCUSSION

As shows table IIa, after race the averaged BM was reduced of 0.6 kg with respect that measured before one. This after-race BM fall could be attributed to a reduction in the body's water content. In fact, Lewis *et al.* [1] had been shown that in sailors exposed from 2 to 3 hours in the sea with a speed wind and a low air temperature, there was a significant reduction of body mass mainly caused by water loss, and this occurred despite not increases in the urine specific density as also occurred in these electric boat's pilots when submitted to the T2 (see table IIb). Cardiodynamic behaviours shown by the variables of interest, along the assessed 10 heart bears in each engaged pilot, indicate a quasi 7% increase in the SV median shown during T2 when compared that in T1. However, probably due to the small number of pilots which it could be able to recruit in the midst of the frenetic activities of several teams involved in the races, this difference did not reach the statistical significance ($P = 0.56$ or neat to what expected for reaching this goal). It must be considered that beat-to-beat SV values result from both central cardiac and peripheral vascular variables. The central/heart-depending variables are in turn due to homeometric or heterometric nature events [31].

The formers depend on intrinsic electromechanical properties of the heart, i.e. the ventricle contractility here achieved by the peak ventricular ejection velocity index (EVI), the second one, also defined as the ventricle pre-load, being related with heterometric mechanisms concerning changes in ventricular diastolic volume, based on the Frank-Starling law [31], up to reach the end diastolic ventricular volume. Moreover, to obtain the systolic ejection flow of the left ventricle also contributes the hydraulic resistance that this blood outflow must overcome to carry the blood towards the vascular periphery, i.e. the so-called total peripheral vascular resistance (PVR) also defined as the ventricular after-load, i.e. as PVR fall the LVEDV increases contributing to enhancing SV and vice versa [7].

Taking into account as stated above, assessed data concerning the left ventricle pre-load, i.e. the LVEDV behaviour as defined figure 4, since its interquartile box in T2 is positioned almost totally above that obtained in T1 giving rise to a statistically significant increase in the median corresponding to T2 compared to that corresponding to T1, this means an high and statically significant reduction in the post race of this cardiodynamic variable. So, as a consequence of the prolonged competition in driving electrical motorboats, there was a significant reduction in left ventricular pre-load and therefore a strong reduction in the central contribution of the heterometric type to the size of the subsequent SV. What above observed can be considered as an expected event probably caused by the poor activation, along the 4 hours of the race, of the so-called muscle pump mainly carried out by the calves rhythmic contractions on the lower limbs veins when walking. In fact, it has been found that the left ventricle pre-load is closely related to the pressure gradient from post-caval vein towards the right atrium which, in turn, depends on the frequency and intensity of lower leg veins squeezing made by *triceps surae* muscles contractions. When occurring, this latter event gives rise to an increase in left ventricle blood filling up to reaching the LVEDV and consequently its contribution to an adequate SV on heterometric basis [7]. It is therefore reasonable to deduce that during the race, due to a prolonged stay in a sitting posture, this gave rise to a scarcely intense and not periodic contractile activity of the pump muscles on the leg veins which, in this way, resulted in the lesser LVEDV here observed [32]. Furthermore, this prolonged postural condition of the pilots might have give rise to transient conditions of relative insufficiency of the venous valves of the legs which could have been maintained even while pilots were performing T2 [33]. However, to support the SV despite the lessening of the LVEDV contribution, in these pilots gave a help the increase in activity of the central homeometric mechanism in terms of a significant increase in myocardial contractility of sympathetic origin [34]. This, increasing the systolic shortening speed of the myocardial fibres, as shown here by the increase in EVI, compensates in this way the function of SV in contributing to have CO values as requested by body organs activities. In fact, as show graphs in figure 8, this latter variable did not fall after the race despite a significant reduction in HR shown in graphs of figure 7. Furthermore, in order to help support the blood flow from the heart to the vascular periphery, during the T2 performance it has been assessed an increase in PVR (figure 6), statistically considerable as almost significant, which gave rise to the detected increase in MABP of 8 *Torr* with respect to the pre-race condition (see table IIa).

Unfortunately, this increase in blood pressure was not supported by the achievement of statistical significance. Graphs in figure 9 highlight an important occurrence that happened in these experiments, i.e. the mechanical efficiency of the heart's left ventricle (LVME), measured in the pilots recruited after they had finished the race with electrical motor boats, was 27% higher than that detected before the race. This bioenergetic variable, although obtained indirectly as a ratio between the LVMW and the clinical indicator of its energy expenditure in terms of its O_2 consumption, i.e. the RPP, was still statistically significant and, therefore, allows to deduce that the psycho-physical activity, delivered during long lasting driving marine vehicles powered by electrical energy originating from green sources, could result in making more efficient aerobic energy substrates for the heart mechanical work delivery. Finally, after a demanding power boating performance such as the Ton's Race in Olbia, the nautical pilots tested here did not show any signs of significant decay in muscular strength nor in respiratory capacity as well as in thermal homeostasis as shown in Tables IIa and IIb by the HGM, PEF and BT tests respectively. Furthermore, it may be that, on the basis of the significant reduction in HR shown as an average of all pilots after the motorboat test, the condition of mild/moderate anxiety manifested in the days preceding this performance from 4 of the 5 pilots here recruited (see the results of the GAD-7 questionnaire in table III), as observed in previous experiments [35], this demanding psycho-physical task could have played a therapeutic role in terms of reducing the previously existing level of anxiety. Therefore it follows that in future research and with adapting numbers of recruited subjects, it is commendable to measure this parameter both before and after a race with electrically power motor boats. In fact, a post-race decrease in anxiety levels in pilots of these boats would be possible given the current data set that agrees with a generalized decrease in orthosympathetic tone.

CONCLUSIONS

Although, to the knowledge of these Authors, there are currently no other experiments regarding the cardio-metabolic adaptations induced by an endurance race with boats electrically powered, there is still a sufficiently robust literature on the people in which the harmful effects that occur when racing with land vehicles powered by endothermic engines, have been studied.

In fact, especially in the context of racing with cars, i.e. formula 1, NASCAR, IndyCar and WEC, the use of internal combustion engines gives rise to well-documented damage in pilots due to the excess concentrations of carbon monoxide (CO) as well as very high temperatures in the restricted cockpit environment together with several organ damage associated with the excess of noise and mechanical vibrations, especially generated by this type of engine [2]. However, the emerging worldwide production for racing series of electric cars, the so-called "Formula E Car Series", by totally eliminating the production of CO, with great advantages also for the natural environment, generate far less heat and emit both little noise and vibrations. It can therefore be reasonably stated that electric vehicles are predicted to greatly reduce driving stress in athletes who dedicate themselves to piloting competitive marine vehicles since this has been clearly demonstrated by the results of this experiment.

In fact, metabolic and cardiodynamic condition which appeared in these 5 pilots after a long lasting physical performance as was that of driving a motor boat engaged in a Ton's Race lasting 4 hours, can be largely assimilated to what is observed after a long-lasting kayaking where, together with a reduction in the percentage of body fat mass [5], there is generally a shift from chronotropic to inotropic control in the cardiovascular beat-to-beat activity. The shown post-race reduction in HR and increase in EVI, both statistically significant, confirm this adaptation which is also in agreement with a likely improvement, in these athletes, in aerobic metabolism which could also justify the observed statistically significant increase in their cardiac mechanical efficiency, and this without any post-race stress of hyperthermic or hypovolemic type, as shown, in turn, by the maintenance of normal values of tympanic temperature (table IIa) and specific urine density (table IIb).

Finally, both the post-race maintenance of a good capacity for producing muscle strength and a good functionality of bronchial flow, as shown in the values of HGM and PEF (table IIb) acquired in the T2 assessments along with a probable anxiolytic action, as the reduced post-race HR seems to accompany, highlight the possibility of using motorboat sports activities based on electric motors powered by green energy, aimed at improving one's physical exercise based on aerobics energy substrates from a health-related quality of life perspective.

STUDY LIMITATIONS

Probably, the most evident limitation of this study is given by the limited number of subjects tested and, within them, also by the wide age range. In fact, this experimentation was carried out, as they say, "directly on the field" without a prior schedule, and so it suffered from a lot of obstacles in the search for pilots who, despite their heavy commitments in preparing for the race, had also to dedicate time to undergo the proposed experimental protocol.

However, given the experimental results acquired here which, in any case, promise that the line of research undertaken can provide important indications on this new sporting specialty, Authors of this work intend to proceed as soon as possible to resume the experimentation with a protocol that includes a larger sample of subjects which would be subdivided into two groups: the one drawing electrically powered boats and the other drawing fossil fuel powered boats, so as to better define what has been acquired here.

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