BIOMECHANICAL AND CARDIOMETABOLIC CHANGES IN A SKILLED KAYAKER AFTER 41 DAYS OF CRUISING AROUND THE ISLAND OF SARDINIA: A CASE STUDY (PART 1)

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BIOMECHANICAL AND CARDIOMETABOLIC CHANGES IN A SKILLED KAYAKER AFTER 41 DAYS OF CRUISING AROUND THE ISLAND OF SARDINIA: A CASE STUDY (PART 1).

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ABSTRACT

47-years old male kayaker Italian instructor, passionate about the sea, circumnavigated the island of Sardinia (Italy) by means of his kayak only covering a total of 969 km in 41 days. Before and after the trip he underwent several medical-biomechanical and nutritional checks: Cardiopulmonary Exercise test up to exhaustion on a kayak ergometer to assess cardiovascular, respiratory and biomechanics variables; echocardiographic measurement of volumes and flows of the heart's left ventricle; body impedance analysis to evaluate body mass and composition. With respect to the tests made before the kayak route the respiratory pattern shifted from frequency to tidal volume dominion, the peak oxygen consumption per kg increased by 13%, the respiratory ratio by 16% and the energy expenditure of about 12%. After the trip the maximum fat oxidation capacity rises 10.5% while the left ventricle stroke volume was augmented by 32%. The decrement in body mass and in waist circumference (both -5%) together with the increase of fat mass in the arms area (+9%) indicate improvements in the athlete's metabolic flexibility.

Keywords: Kayaking, cardiopulmonary test, stroke volume, body impedance analysis, metabolic flexibility

1 INTRODUCTION

In recent years, in parallel with the increase in the practice of kayaking as a sport, research on the biomechanical and physiological components of this sport has increased with the aim of helping coaches in the development of specific training programs [1].

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However, it was dedicated scarce attention to the energetic and metabolic functional level requested by kayaking to avoid unpleasant symptoms like dehydration, arrhythmia or dyspnoea. Nevertheless, some studies recently published have shown several and important beneficial effects that concern athletes who practice sailing sports especially in endurance and touristic-naturalistic performances [2-6]. On the other hand, previous studies have highlighted some risks due to prolonged sailing in the sea like as hyperglycaemia and dehydration, up to physical and mental health diseases due to going to sea [7]. We supported scientifically and technologically a well-known and very experienced kayaker in circumnavigating the Sardinia for many hundreds of kilometres, planning to paddle an average of 20 - 40 kilometres per day.

The aim of the research was to study the possible physical adaptations which could occur resulting from this prolonged effort. To enable real-time remote acquisition of biophysical data, we developed an optimized version of our telemedicine platform, i.e. the E-Physio Tool [5, 8, 9, 10, 11, 12], adapted for use in heavy resource-limited settings, such as on a kayak. In particular, the client side of the platform was redesigned to operate in a highly integrated mode, consuming minimal energy while still capable of supporting telemedicine activities and the routine communication needs of the vessel. For this enterprise with strong scientific connotations both the Polytechnical University of Turin and the Sardinian Agency for Research and Technology Development of Cagliari (Italy), have granted their free patronage.

2 METHODS

2.1 THE ATHLETE

The athlete is 47-year-old male which is a federal rowing instructor in Italy and sea passionate. He circumnavigated Sardinia Island, in Italy in the middle of the west side of the Mediterranean Sea, by his kayak, in almost six weeks of sailing, covering a total of 969 km in 41 days. The coastal cruise, made on a kayak model 535 from the Diana Canoe Manufactures, in Italy, was not only for sports reasons but also for tourist and naturalistic leisure with the aim of sensitizing the inhabitants of various coastal towns to ecological activities such as cleaning the beaches where it was located from plastic materials. All this led to several stops, even for a few days, during the route. The departure was on 2024 March 26 from the small port of Marina Piccola in Cagliari, Italy, where he completed the circumnavigation of the island by landing in 2024 May 5. Before embarking on the coastal route and after disembarking upon returning to Cagliari, he underwent a series of medical-biomechanical-nutritional checks, at the Sporting Life & Medicine Lab of the Sardegna Ricerche (SLAM) and at the Sports Nutrition Laboratory of the postgraduate school in Sports Medicine of the University, in Cagliari, Italy.

2.2 EXPERIMENTAL PROTOCOL

2.2.1 ICT platform

The ICT platform designed for monitoring the kayak's navigation consisted essentially of three main components.

a) the client side, composed of the following elements: a smartphone with deeply modified system software, serving as the primary client unit, responsible for supporting all bidirectional data transmission activities, including data from bio signal acquisition devices plus standard telecommunication functions of the vessel, and geospatial tracking of the kayak; an Energy Storage System (ESS) made up of a micro storage system (consisting of lithium batteries), a Battery Management System (BMS), and a high-efficiency solar panel designed for prolonged marine use; sensing devices for acquiring bio signals and physical measurements, operating in on-demand mode (biomedical devices) and continuous mode (positional tracking, thermo-hygro-barometric environmental data acquisition);
b) a data network composed by digital telephonic lines (mainly 3G, 4G and 5G connections);
c) a server-side component capable of receiving data in real time as well as in batch transmissions (in case of a missing data connection on the client side), and storing and processing all relevant information.

2.2.2 Medical-Biomechanical-Nutritional Check

Just before and after the kayaker was embarking on his cruise around Sardinia, the athlete was subjected to the following three types of tests:

1. Cardiopulmonary Exercise test (CPET);
2. Echocardiogram Colour Doppler test (ECDT);
3. Anthropometric variables measurements (ANTP).

By an ergometric station with a specific kayak ergometer which paddle resistance was manually increased each two minutes from a constant value, together with a breath-by-breath gas-analyser model Q - NRGmax + (Cosmed, Italy), a CPET incremental test was performed by the athlete while he kept a constant frequency of paddling: about 60/min up to exhaustion (see figure 1), and the variables described below were achieved before the test beginning and at the peak workload.

Figure 1 The athlete while paddling on the kayak lab simulator is shown. The bar he holds simulates the paddle in the act of pushing it down and back with his right hand. It is attached to the manually variable mechanical resistance system located in the anterior side of the ergometer by two ropes at the ends. On his face, the athlete wears a mask connected, by thin tubes, to the gas analyser for collecting respiratory and metabolic variables as: oxygen consumption, carbon dioxide production and pulmonary ventilation.

The test ceased after 16 minutes when the athlete was no longer able to maintain the imposed paddling pace. The maximum paddling time and the number of steps (8) were the same in both tests (before and after the coastal route). The following variables were assessed:

a) pulmonary ventilation together with tidal volume and breath frequency,
b) oxygen consumption, carbon dioxide production and respiratory ratio,

c) inspiratory and expiratory ratios for oxygen consumed and carbon dioxide produced,
d) energy expenditure per minute,
e) maximum fat oxidation.

By utilizing an echocardiographic device model MyLab30CV (EsaOte, Italy), the following ECDT measurements were taken at rest:

a) left ventricle end-diastolic volume (EDVLV),
b) left ventricle end-systolic volume (ESVLF),
c) left ventricle stroke volume (SVLF),
d) left ventricle ejection fraction in % (EFLV%).

By utilizing both a device for the body impedance analysis (BIA) model: Akern BIA 101 (Akern, Italy) and the skin plicometry, the following anthropometric variables were taken at rest before and after the test:

a) body mass (BW),
b) fat mass and fat free masses (FM & FFM),
c) total body water (TBW),
d) waist circumference (WC),
e) muscle arm area (AMA),
f) fatty arms area (AFA).

3 RESULTS

Data concerning results pertinent to the operating ICT platform will be reported in the part 2 of this research (which will be published as soon as possible) along with all the other data, both biological and physical, acquired through this platform by the boat-subject duo in navigation. Here we reported only data from test performed by the athlete before and after the cruise.

3.1 CPET RESULTS

Tables 1 and 2 show data corresponding to tests assessed from the athlete respectively before kayaking (T1) and after this exercise (T2). Both these Tables show, respectively, data acquired before (rest) and at the maximum workload of the exercise (peak). In figure 2, for greater clarity, the same variations are represented in the form of a histogram.

Table 1 shows that the rapid shallow breathing index [13] at rest, i.e. [RSBI = Rf * Vt^{-1} (L min^{-1})], in T1 was 10.6 L min^{-1} while in T2 was 27.5 L min^{-1}. This occurrence before the T2 beginning may indicate a respiratory pattern adaption, from amplitude to frequency of breaths dominion, due to a long-time kayak practice. In fact, at low ventilatory demand, the energy expenditure to overcome the inspiratory elastic resistances was reduced, giving rise to an energy saving in the respiratory cycle and therefore, an oxygen sparing effect [14], and this may occurred practically with no changes in T2 versus T1 rest values of the Ve. The prolonged physical paddling by kayak also determined advantages at rest in the metabolic variables, as shown in Table 1 (rest-T2), since both VO_2 and VO_2/kg as well as VCO_2 were reduced while maintaining the RQ constant. So long as in T2 the variations at rest of Ve/VO_2 and Ve/VCO_2 were increased compared to T1, this shows a greater increase of the reflex efficiency of athlete's control systems of Ve by the arterial partial pressures of VO_2 and VCO_2 [15, 16].

Referring to Table I and II: Rf = respiratory frequency, Vt = tidal volume: Ve = pulmonary ventilation, VO_2 = oxygen consumption, VCO_2 = carbon dioxide production, RQ = respiratory ratio, EEm = energy expenditure, Ve/VO_2 and Ve/VCO_2 = respectively ventilatory equivalents for oxygen and carbon dioxide. Δ% intensities of T2 respect to T1 are highlighted by green-red different colours intensity.

Table I - Rest condition before the CPET

Variables	Dimension	Rest-T1	Rest-T2	Δ%
Rf	1/min	11.2	17.9	59,8
Vt	mL	1057	653	-38.2
Ve	L/min	11.8	11.7	-0,8
VO_2/Kg	mL/Kg/min	6.2	5.3	-14.5
VO_2	mL/min	445	365	-18.0
VCO_2	mL/min	325	267	-17.8
RQ	-	0.73	0.73	0,0
EEm	kcal/min	2.14	1.76	-17.8
Ve/VO_2	-	27	32	18.5
Ve/VCO_2	-	36	44	22.2

Table II - Peak condition during the CPET.

Variables	Dimension	Peak-T1	Peak-T2	Δ%
Rf	1/min	40.4	30.1	-25.5
Vt	mL	1871	2946	57.5
Ve	L/min	75.6	88.7	17.3
VO_2/Kg	mL/Kg/min	33.9	38.2	12.7
VO_2	mL/min	2410	2598	7.8
VCO_2	mL/min	2552	3185	24.8
RQ	-	1.06	1.23	16.0
EEm	kcal/min	12.25	13.68	11.7
Ve/VO_2	-	31	34	9.7
Ve/VCO_2	-	30	28	-6.7

This also implies a metabolic-respiratory adaptation towards a greater sensitivity of this mechanism which, again, must be attributed to the long period of almost continuous daily kayak exercise. The resting metabolic advantage due to the endurance exercise is further reinforced by comparing to T2 to T1 both the EEm and calculated Fat oxidation (FatOx) [17], which were significantly reduced. This could be related to a better, after paddling, athlete's oxidative metabolism at rest, so that the partial pressure of the CO_2 at the pulmonary capillary circulation level could be reduced [15].

As shows table 2, at the peak effort on the kayak ergometer the athlete showed both in T1 and T2 a respiratory pattern shifted towards highest Rf and Vt. However, while the peak RSBI in T1 was almost doubled (21.6 L min^{-1}) respect to that at rest, this variable in T2 was quasi a third of the value found at rest (10.2 L min^{-1}).

This evidence agrees with a shift towards the chest's volumes increases rather than breathing rates one in increasing the Ve [14]. In fact, in T2 there was a shift towards the inspiratory chest volume increases (energy expenditure due to elastic resistance from tissue distension) rather than breathing rates (energy expenditure due to viscous resistance from speed cycles) showed by our athlete in increasing the Ve at the peak workload. Since the energy cost spent to win the viscous resistance is unitarily higher than the one spent to win the elastic resistances [14], then choice of favour changes in Vt rather than in Rf was the more economic breathing pattern when highest Ve demand was request [18]. Considering now the biometabolic-biomechanic variables, it can be observed that, reaching the peak workload, in T2 condition compared to the T1 one clearly results higher values in these parameters. In fact, this increase in almost all variables of interest exceeded 10% respect to the first CPET. Interestingly, the Ve/VCO_2 assumed quasi similar values in both tests peak values.

Concerning the bioenergetic performances, here it has been found that the anaerobic threshold (AT) in T1 appeared at a VO_2 of 29.5 mL/kg which was the 87% of the peak one while in T2 the AT was reached at a VO_2 of 34.4 mL/kg or at 90% of the corresponding peak VO_2. This, in a way that leaves no doubt, demonstrates that our athlete's maximum aerobic capacity increased remarkably after 41 days of coastal cruising. All these findings agree with the observation, during the CPET, of maximum FatOx values that in T1 coincided with a VO_2 of 24.9 mL/kg while in T2 this capacity reached a VO_2 of 27.5 mL/kg or 10.5% higher than the former one and, furthermore, the RQ in T2 (1.23) exceeded by 16% that observed in T1 (1.06).

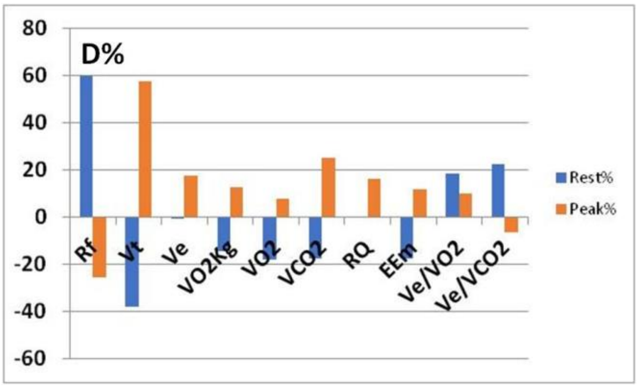

Figure 2 For each variable considered columns graphically represent % differences acquired at the T2 with respect the T1 at each test's condition considered.

3.2 ECDT RESULTS

Echo-cardio Doppler measurements (ECDT) have been made just before each CPET by a skilled doctor while the athlete was quiet at rest and in a semi-supine position on a medical examination table. Data from these measurements are shown in Table III.

Table III - Values of the echocardiographic variables assessed at rest respectively before the T1 and T2. Reported values concern the subject's left ventricle of the heart

Variables	Dimension	Rest-T1	Rest-T1	Δ%
End Diast. Volume	mL	80.2	101.7	+26.8
End Syst. Volume	mL	40.6	49.6	+25.2
Stroke Volume	mL	39.7	52.1	+31.2
Ejection Fraction	%	49	51	+4.1

With respect to T1 condition, in the T2 one there were relevant increases in all the four fundamental variables concerning the cardiodynamic activity here reported, which are functional to the aerobic-oxidative metabolic adaptations proposed above. In fact, an increase of more than 25% in the left ventricle end diastolic volume indicates a clear, heterometric adaptation, in the regulation of the SV of the Frank-Starling-type dependent, but the increase of about 4% of the systolic ejection fraction also indicates an adaptation in the regulation of the SV of the homeometric-type-noradrenergic dependent one [19]. Hence the notable increase in SV itself, over 30%, already in resting conditions observed before T2 compared to T1.

3.3 ANTP RESULTS

Anthropometric variables assessed in our athlete are shown in table 4. It can be observed that, after 41 days a weight loss of 3.5 kg occurred mainly due to a 1.6 kg reduction in FM (about -13%) and in 1.9 kg in FFM (about -3%) of the pre cruise measurement. Interestingly, in the second ANTP measurements there was a reduction in the WC of quasi 5% respect the first one and an increase of AFA of about 9% (all obtained by plicometry measurements). These anthropometric changes occurred to our athlete after his long kayaking performance agree both with corresponding increases in peak VO_2 and in peak FatOx which all together are closely linked with reduced FM and, consequently, reduction in both BW and WC [20].

Table IV - Anthropometric variables assessed by BIA and plicometry* methods. BW: body weight, FFM: free fatty mass, FM: fatty mass, TBW: total body water, AMA: arm muscle area, AFA: arm fatty area, WC: waist circumference.

Tests	Variables						
	BW (kg)	FFM (kg)	FM (kg)	TBW (kg)	AMA* (cm^2)	AFA* (cm^2)	WC* (cm)
T1	70.2	57.7	12.5	42.3	63.6	8.0	84.0
T2	66.7	55.8	10.9	40.8	62.9	8.7	80.0
Δ%	-5.0	-3.3	-12.8	-3.6	-1.1	8.7	-4.8

4 DISCUSSION

Data showed in this study agree with previously observed [3, 5], i.e. that long lasting sea coastal cruising in a boat gives rise to several benefits concerning the so-called health-related quality of life (HRQoT). In fact, the here studied kayaker after almost six weeks of staying in coastal areas, mostly paddling on his boat, showed clear benefits at the level of various organs and systems. In the respiratory system, where a significant variation in its pattern was observed, this favoured in this way the reduction of the energetic cost of this very important and expensive homeostatic function. In fact, the RSBI in T2 condition, compared with that in T1 one, might refer for a blue coastal spaces training-induced adaptation of the brain stem centre for breathing modulation [21]. About this, it could be considered the possible occurring of a relative arterial CO2 increasing for the happening peak respiratory super-compensation, i.e. a relative alveolar hypercapnia. As is known [10] this respiratory super-compensation takes place when the workload overcomes the value corresponding to the AT. This has the target of avoiding a fall in the blood's pH caused, in turn, by the excess of lactic acid which spill from working muscle cells into the bloodstream. Since it has been suggested that a relative hypercapnia could induce a reduced excitability in the lungs stretch receptors [22], the effect of these down-excited receptors is a reduction of their reflex volley of action potentials towards the brain stem which results in prolonging the inspiration [23]. This occurrence could produce in our kayaker, performing the CPET after cruise, an increase in the volume and duration of the breaths as was this here observed increase of peak Vt together with the fall of peak Bf. Therefore, it is reasonable to suppose that the adaptation of the breathing pattern, could have the purpose of reduce the viscous resistance in the breathing cycles with a lower mechanical work to be spent from respiratory muscles, i.e. a not negligible aerobic energy saving. Furthermore, in our paddling athlete was ameliorated the so-called metabolic flexibility (MF) i.e. the ability of an organism to maintain the homeostasis by providing fuel supply for different physiological conditions [17, 24]. Thus, MF could be here considered as a system with cooperating features in managing body energy reserves and requirements in the case of increasing muscle power demand, has happened in our athlete.

An unquestionable sign of the fact that our athlete's MF improved due to the Sardinia Island circumnavigate in a kayak, comes from the observation that the lipid component of the subcutaneous area of the arms had increased by almost 9% compared to the pre-cruise condition [25, 26]. In fact, a previous research has highlighted that pathologies that induce a metabolic rigidity, such as diabetes mellitus, are also marked by a reduction in perimuscular lipid mass and an increase in visceral fat [12], exactly the opposite of what occurred in our athlete in whom, after prolonged exercise, an increase in fat in the arms and a reduction in visceral fat was observed, as shown by the fall in the WC.

It is remarkable to note that, because it has been found that moving while paddling within the sea aerosol (into which active peptides and like ACE inhibitor molecules from dead marine organisms) could preserve from tumoral and cardiovascular diseases [27, 5], as well as here indicated to our kayaker as some fundamental behaviours to acquire functional aliments into his daily diet on the basis of the nutritional principle for athletes [28]. In conclusion, it could be reasonable to state that a long-lasting paddling in kayak was able to ameliorate the HRQoT. This is consistent with what has already been demonstrated previously with regards to the optimisation of working environments through advanced lighting technologies [29].

EXPERIMENTAL LIMITATIONS

In our report only one athlete was examined. However, the current lack of knowledge of the adaptations due to long-lasting physical activity by paddling give a non-negligible impulse to deepen this knowledge.

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