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Physiological Response and Sports Injury Risk Relevant Biomechanics in Endurance Obstacle Course Races

Jorge Rey-Mota [1], David Martín-Caro Álvarez [2,*], Ana Onate-Figuérez [2], Rodrigo Yañez-Sepúlveda [3] and Vicente Javier Clemente-Suárez [1,4]

1 Faculty of Sports Sciences, Universidad Europea de Madrid, Tajo Street, s/n, 28670 Madrid, Spain; jreymota@gmail.com (J.R.-M.); vctxente@yahoo.es (V.J.C.-S.)
2 Toledo Physiotherapy Research Group (GIFTO), Faculty of Physiotherapy and Nursing of Toledo, Universidad de Castilla-La Mancha, 45071 Toledo, Spain; ana.onate@uclm.es
3 Faculty of Education and Social Sciences, Universidad Andres Bello, Viña del Mar 2520000, Chile; rodri-go.yanez.s@unab.cl
4 Grupo de Investigación en Cultura, Educación y Sociedad, Universidad de la Costa, Barranquilla 080002, Colombia
* Correspondence: david.martincaro@uclm.es; Tel.: +34-925268800

Abstract: Obstacle course races (OCR) have experienced significant growth in recent years, with millions of participants worldwide. However, there is limited research on the specific physiological demands and injury prevention strategies required for these events. This study aimed to analyze the physiological responses and injury risks in participants of a 5 km (Sprint) and 13 km (Super) OCR. Sixty-eight participants were assessed for cortical arousal, leg strength, isometric handgrip strength, blood lactate, heart rate, blood oxygen saturation, body temperature, urine composition, spirometry values, hamstring flexibility, lower limb stability, foot biomechanics, and scapular kinematics, one hour before and immediately after the races. The results showed a significant decrease in leg strength (Sprint: r = −0.56, $p < 0.01$; Super: r = −0.54, $p = 0.01$) and urine pH (Sprint: r = −0.70, $p = 0.03$; Super: r = −0.67, $p = 0.01$) in both distances, with increases in urine colour, protein, and glucose (Sprint: $p < 0.04$). In the 13 km race, lower limb stability decreased significantly post-race (r = −0.53, $p = 0.01$). Positive correlations were found between performance and pre-race handgrip strength (Sprint: r = 0.71, $p = 0.001$; Super: r = 0.72, $p = 0.01$) and spirometry values (FVC, FEF 25–75%, FEV1) (Sprint: r = 0.52, $p = 0.031$; Super: r = 0.48, $p = 0.035$). Thermoregulation capacity, reflected in a higher pre-race body temperature and lower post-race body temperature, also correlated with improved performance (r = 0.49, $p = 0.046$). Injury risk increased post-race, with a significant decline in lower limb stability ($p < 0.05$). These findings highlight the importance of targeted training programs, focusing on grip strength, leg strength, respiratory muscle training, and hydration strategies to optimize performance and reduce injury risk in OCR athletes.

Keywords: physiology; training; physiotherapy; performance; running; strength

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1. Introduction

Obstacle course races (OCR) have experienced a large growth in the number of participants and competitions in the last few years. It is estimated that more than 4.2 million people participated in an OCR in 2014 in more than 30 countries all over the world [1]. The races manage distances from 5 km to marathon lengths with 10 to over 100 obstacles, respectively. The most popular challenges cover 5 km, with 10–15 obstacles, and 13 km with 15–25 obstacles. The obstacles include climbing ropes and walls, crawling through mud pits with barbed wires, running through fire, swimming in freezing waters, carrying heavy loads, and even sometimes passing through electrified cables.

The physiological requirements for this new sports modality are based on a combination of anaerobic and aerobic pathways [1,2]. The maximum volume of oxygen (VO_2max) is highly correlated with aerobic performance, especially when they involve passing through obstacles and carrying heavy loads [2,3] because it allows individuals to keep a greater running pace and recover quickly after the obstacles [2–4]. The VO_2max is also a performance indicator for lactic anaerobic efforts [4]. This is important because lactic and phosphocreatine organic systems are challenged when passing obstacles. Running economy and lactate threshold are also well correlated with endurance performance, so it is important to include specific training sessions in their development [5,6]. Thus, muscular strength (both lower and upper body), speed, and endurance, added to the high demands of balance and coordination, which are all related to the maintenance of optimal cortical arousal [7], are determinant factors related to OCR performance [1]. Other crucial factors are optimal hydration levels, since this OCR probe could take more than 1 h to complete, and the nitrates, pH, protein, and glucose in the urine, which can be very influenced by the requirements of the race [8].

To successfully complete an OCR, athletes must undergo highly intense and cross-training programs [1]. It has been demonstrated that large training loads make competitors vulnerable to injuries [9], and experienced athletes are less affected by injuries [10]. The most predominant occur in the lower limbs because of overuse and/or altered biomechanics during running, and the risk of suffering them can be predicted by conducting some simple field tests such as one-leg standing test [11], navicular drop test [12], Jack's test [13], and active straight leg raise test [14]. But, upper extremities injuries can also be present in this sports modality because of the suspension obstacles, so the assessment of scapular kinematics [15] and isometric hand grip strength could be interesting [16,17].

When analysing the previous literature on OCR, we found little evidence to support specific training for them based on the real physiological requirement of these special probes. Thus, we propose the present research to study the physiological and psychological demands and injury risk in OCR with the following objectives: i. to study the physiological response in a Sprint (5 km) and Super (13 km) obstacle course race; ii. to analyse the differences in the physiological response between Sprint and Super OCR; iii. to analyse injury patterns in Sprint and Super OCR; iv. to analyse the correlation between the physiological and injury risk variables with performance in Sprint and Super OCR. The initial hypothesis was that Sprint OCR would achieve a higher anaerobic metabolism activation, and Super OCR would achieve higher degrees of stress manifestations and dehydration. This information could be used by trainers and health care professionals to improve the efficient design of training programs and injury prevention plans.

2. Materials and Methods

2.1. Experimental Approach to the Problem

The physiological and physical exertion in OCR can influence the final performance of the athletes and the risk of injuries. Therefore, the current descriptive study aimed to analyse the physiological requirements and injury-related parameters of the probe to better understand the demands of obstacle course races so practitioners could design efficient and effective interventions for athletes. To our knowledge, no research exists in this area that has a deep analysis of physiological and physical variables.

2.2. Subjects

We analysed 66 volunteer participants in a Spartan Race competition of 5 km (Sprint distance) and 13 km (Super distance) in Valencia, Spain. Twelve men (30 ± 8 years, 179 ± 9.86 cm, 76 ± 9.21 kg, and 23.56 ± 1.41 BMI) and eleven women (32 ± 7 years, 165 ± 5.54 cm, 58 ± 9.2 kg, and 21.29 ± 2.63 BMI) took part in the Sprint distance, and thirty-six men (30 ± 6 years, 176 ± 5.8 cm, 77 ± 7.56 kg, and 24.68 ± 2.05 BMI) and seven women (31 ± 7 years, 163 ± 5.26 cm, 59 ± 8.43 kg, and 22.1 ± 2.5 BMI) took part in the super distance.

2.3. Procedures

Prior to starting the research, the experimental procedures were explained to the participants, who gave their voluntary written informed consent in accordance with the Helsinki Declaration, ensuring ethical standards were met, with ethical approval granted by the European University's Bioethics Committee under code CIPI/18/074. Then, the following variables were measured the hour before the race and immediately after finishing the race.

Cortical arousal was analysed through the critical flicker fusion threshold (CFFT) in a viewing chamber which was constructed to control extraneous factors that might distort CFFT values (Lafayette Instrument Flicker Fusion Control Unit Model 12021) following the procedures conducted in previous studies [18,19]. An increase in CFFT suggests an increase in cortical arousal and information process; by contrast, when the values fall below the baseline, it suggests a reduction in the efficiency of processing information and fatigue of the central nervous system [7].

Blood oxygen saturation (BOS) and heart rate (HR) were measured with a pulse oximeter (PO 30 Beurer Medical) following previous procedures [20].

Body temperature (BT) was measured with a digital infrared thermometer (Temp Touch; Xilas Medical, San Antonio, TX, USA) following previous authors [21,22].

Lower body muscular strength manifestation was analysed using a vertical jump test. We used the Sensorize FreePowerJump system (SANRO Electromedicina, Madrid, Spain), which recorded flight time (s) and jump height (cm) to evaluate 2 vertical types of jump following previous protocols [23,24]. Participants performed 2 Contramovement Jumps (CMJ) and 2 Abalakov jumps (ABK), as in previous research [19,25]. The coordinative capabilities and arms utilization capacity (CCA) were also analysed using the Bosco formula (1999) (CCA= ABK − CMJ)

Upper body muscular strength manifestation was analysed by testing the isometric hand strength (IHS) with a grip dynamometer (Takei Kiki Kogyo, Tokyo, Japan). Two repetitions were performed with the dominant hand, and the best one was chosen in line with previous research where performance was measured [26,27].

The blood lactate concentration was measured by taking a sample of 5 µL of capillary blood from a finger and analysed with the validated Lactate Pro Arkay, Inc. system (Kyoto, Japan) according to previous research [28].

Urine samples were collected to analyse dehydration levels, which were examined against a urine colour chart (colour range 1–8, where 1 = very pale yellow urine, which reflected a good level of hydration, and 8 = very dark yellowish brown, which reflected a significant level of dehydration); the number closest to the sample colour was recorded [29]. Urine nitrates, protein, glucose, and pH were measured with the Orine Combur Test (Roche, Madrid, Spain) stripes. The rate of perceived exertion (RPE) was measured with a Borg 6–20 scale [30].

Spirometry values of forced vital capacity (FVC), forced expiratory volume in 1 s (Fev1), and forced expiratory flow 25–75% (FEF25) were measured using a CPX device (Medical Graphics Corporation, St. Paul, MN, USA) performing maximum inhale-exhale–inhale cycle as previous research [31].

Kinematics of the scapula were measured with a scapular dyskinesis test. Participants performed 3 shoulder 180° flexions and 3 shoulder 180° abductions. Values were classified into 3 grades: normal pattern, subtle dyskinesia, and evident dyskinesia [15].

Lower limb stability was measured with the 1-leg standing test (1LST). Participants performed one repetition of 30 s with each leg at 90° of hip and knee flexion with their eyes closed. Values were also classified into 3 grades: I. The athletes remained the whole 30 s without falling, collapsing their hips (Trendelemburg sign) or pivoting with their feet, which indicates good stability; II. The athletes remained the whole 30 s, but their hips collapsed and/or feet pivoting occurred, which indicates poor stability; III. The athletes were unable to hold the position for 30 s, which indicates very poor stability.

Plantar arch stability was measured with the navicular drop test [12]. Navicular height was measured with a 66 fit commercial house goniometer on both feet in a seated position and in a standing position. The difference between the seated and standing positions indicates the navicular drop in charge.

The windlass mechanism was measured using Jack's test [13]. The athletes performed 2 trials of active dorsiflexion of the first metatarsophalangeal joint, and we evaluated its range of movement (ROM) with a 66 fit commercial house goniometer, the increment of the plantar arch's height, and the reposition of the tibia over the astragalus.

Lower limb posterior chain flexibility was measured with an adaptation of the active straight leg raise test [14]. Participants performed one repetition with each leg of active hip flexion with knee extension, and the range of movement was measured with the 66 fit commercial house goniometer.

2.4. Statistical Analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS) version 21 (SPSS Inc., Chicago, IL, USA). Means and SDs were calculated using traditional statistical techniques. Normality and homoscedasticity assumptions were tested with the Kolmogorov–Smirnov test. A one-factor ANOVA for intergroup comparisons and a Student's *t*-test for intragroup comparisons, since variables presented a parametric distribution, were conducted. The effect size was calculated using Cohen's d formula, which is defined as the difference between two group means divided by the pooled standard deviation. In terms of the variables presented in the charts, this calculation allows us to quantify the magnitude of differences between the pre- and post-race measures for both the control (baseline) and experimental (post-race) conditions. A positive effect size indicates that the mean post-race value is higher than the pre-race value, signifying an increase in the variable (e.g., blood lactate or rate of perceived exertion) as a result of the race. Conversely, a negative effect size indicates a decrease in the post-race mean compared to the pre-race mean, such as the observed decreases in leg strength or stability. In terms of interpreting the magnitude of effect sizes, we followed the conventional benchmarks where an effect size of 0.2 represents a small effect, 0.5 is a medium effect, and 0.8 or greater is a large effect. For example, in the sprint race, the decrease in leg strength had a medium to large effect ($d = -0.56$), while the increase in urine glucose showed a large effect ($d = 3.00$). The significance level was set at $p < 0.05$.

In addition, A post hoc correlation analysis was conducted to assess the relationships between key pre- and post-race physiological variables. Pearson's correlation coefficients were calculated to determine the strength and direction of associations between pre-race and post-race measures, including countermovement jump (CMJ), Abalakov jump (ABK), upper body coordination and grip strength (CCUB), forced vital capacity (FVC), and forced expiratory volume (Fev1). The analysis was performed using a two-tailed significance level of $p < 0.05$. This approach allowed us to explore how pre-race performance indicators predicted post-race outcomes, providing deeper insight into the physiological responses of athletes during obstacle course racing.

Finally, a linear regression analysis was conducted to assess the predictive power of pre-race physiological measures on post-race countermovement jump (CMJ) performance. The independent variables included pre-race CMJ, Abalakov jump (ABK), upper body coordination and grip strength (CCUB), forced vital capacity (FVC), forced expiratory volume (Fev1), and FER25. The dependent variable was post-race CMJ. The dataset was split into training (80%) and testing (20%) sets, and the model's goodness of fit was evaluated using R-squared. The regression coefficients were analyzed to determine the influence of each predictor on post-race performance.

3. Results

In the SPRINT distance, there was a significant decrease in CMJ, ABK, pH and RJack. On the contrary, heart rate, lactate, RPE and urine colour, protein, and glucose presented a significant increase (Table 1). In the SUPER distance, we found significant decreases in CMJ, ABK, CCA, Fev1, pH, and RDrop and significant increases in heart rate, lactate, RPE, LST, RST, and colour (Table 2).

Table 1. Pre-post results of Sprint OCR (5 km).

	Pre	Post		Cohen's D	95% Confidence Interval			
Variable (Unit)	**Mean ± SD**	**Mean ± SD**	**% Change**		**Inferior**	**Superior**	**T**	***p***
CMJ (m)	36.88 ± 6.37	33.29 ± 4.63	−9.73	−0.56	2.25	4.92	5.69	0.00
ABK (m)	42.59 ± 9.02	39 ± 5.48	−8.43	−0.40	0.9	6.28	2.83	0.01
CCA	5.71 ± 4.33	5.71 ± 3.04	0.00	0.00	−1.98	1.98	0	1
FVC (mL)	4.91 ± 1.61	4.28 ± 1.2	−12.83	−0.39	−0.05	1.32	1.98	0.07
Fev1 (mL)	4.06 ± 3.26	3.59 ± 1.19	−11.58	−0.14	−0.95	1.91	0.71	0.49
FEF25 (mL)	7.41 ± 3.35	8.27 ± 3.69	11.61	0.26	−2.72	1.01	−0.97	0.35
HR (bpm)	83.12 ± 16.44	103 ± 16.51	23.92	1.21	−32.93	−6.83	−3.23	0.01
BOS (%)	97.41 ± 1.5	97.18 ± 2.43	−0.24	−0.15	−1.06	1.53	0.39	0.71
BT (°C)	35.78 ± 1.81	30.64 ± 10.84	−14.37	−2.84	−0.76	11.03	1.85	0.08
IHS (kg)	39.53 ± 12.07	38.12 ± 14	−3.57	−0.12	−1.63	4.45	0.98	0.34
Color (au)	3.92 ± 1.94	7 ± 0.91	78.57	1.59	−4.17	−1.99	−6.16	0
Ph	5.62 ± 0.77	5.08 ± 0.28	−9.61	−0.70	0.07	1.01	2.5	0.03
Protein (mg/dL)	0.08 ± 0.28	0.92 ± 0.64	1050.00	3.00	−1.33	−0.36	−3.81	0
Glucose (mg/dL)	0 ± 0	0.31 ± 0.48	inf	0.10	−0.6	−0.02	−2.31	0.04
RPE	6 ± 0	13.06 ± 2.1	117.67	0.10	−8.1	−6.01	−14.26	0
Lac (mmol)	0.56 ± 0.26	9.44 ± 4.97	1585.71	34.15	−11.47	−6.3	−7.29	0
LST	1.82 ± 0.39	1.71 ± 0.69	−6.04	−0.28	−0.32	0.56	0.57	0.58
RST	1.77 ± 0.56	1.71 ± 0.69	−3.39	−0.11	−0.44	0.56	0.25	0.81
LFlex (°)	78.88 ± 12.61	77.47 ± 12.64	−1.79	−0.11	−3.93	6.75	0.56	0.58
RFlex (°)	80.65 ± 14.33	76 ± 11.73	−5.77	−0.32	−1	10.3	1.74	0.1
LDisk	1 ± 0.82	1.63 ± 2.13	63.00	0.77	−1.67	0.42	−1.27	0.22
RDisk	1 ± 0.87	1.59 ± 2.06	59.00	0.68	−1.69	0.52	−1.13	0.28
LJack	0.65 ± 0.49	0.47 ± 0.52	−27.69	−0.37	−0.38	0.03	−1.85	0.08
RJack	0.65 ± 0.49	0.41 ± 0.51	−36.92	−0.49	0.01	0.46	2.22	0.04
LDrop (cm)	0.44 ± 0.19	0.44 ± 0.14	0.00	0.00	−0.13	0.12	−0.05	0.96
RDrop (cm)	0.47 ± 0.22	0.49 ± 0.23	4.26	0.09	−0.19	0.16	−0.21	0.83
CFFT (ms)	37.02 ± 3.26	37.09 ± 2.93	0.19	0.02	−1.61	1.46	−0.1	0.92

Countermovement jump (CMJ), Abalakov jump (ABK), coordinative and arm-using related capacities (CCA), forced vital capacity (FVC), Forced Espiratory Volume in the 1st second (Fev1), Forced Espiratory Flow between 25 and 75% of forced vital capacity (FEF25), heart rate (HR), blood oxygen saturation (BOS), body temperature (BT), isometric hand strength (IHS), rate of perceived exertion (RPE), lactate (Lac), left leg stability (LST), right leg stability (RST), left leg flexibility (LFlex), right leg's flexibility (RFlex), left scapular dyskinesis (LDisk), right scapular dyskinesis (RDisk), left foot Jack's test (LJack), right foot Jack's test (RJack), left foot navicular drop (LDrop), right foot navicular drop (RDrop), critical flicker fusion threshold arousal (CFFT).

In the intergroup ANOVA analysis, we found statistical differences in the parameters of lactate post (p: 0.001), urine colour post (p: 0.017), urine protein post (p: 0.04), urine glucose post (p: 0.029), pre navicular drop in the left (p: 0.029) and right (p: 0.008) feet, and dominant leg stability post (p: 0.036).

The full correlation analysis could be check in the Supplementary Materials (Tables S1–S4). Specifically, in the 5 km Sprint distance, the following positive bivariate correlations were found: Probe time positively correlated with pre-exercise heart rate (HR pre, r = 0.471, p = 0.031) and post-exercise body temperature (BT post, r = 0.508, p = 0.032). Pre-exercise left leg stability (LST pre) correlated with post-exercise forced vital capacity (FVC post, r = 0.523, p = 0.031), and pre-exercise right leg stability (RST pre) also correlated with FVC post (r = 0.509, p = 0.037). Pre-exercise left leg flexibility (LFlex pre) correlated with post-exercise heart rate (HR post, r = 0.490, p = 0.046), and pre-exercise left scapular dyskinesis (LDisk pre) correlated with pre-exercise forced expiratory volume in 1 s (Fev1 pre, r = 0.493, p = 0.027). Pre-exercise right scapular dyskinesis (RDisk pre) correlated with post-exercise heart rate (HR post, r = 0.503, p = 0.040). Pre-exercise left foot navicular drop (LDrop pre) correlated with pre-exercise pH (pH pre, r = 0.526, p = 0.025), and post-exercise left scapular dyskinesis (LDisk post) correlated with pre-exercise glucose levels (Glucose pre, r = 0.933, p = 0.000). Post-exercise right scapular dyskinesis (RDisk post) correlated with pre-exercise body temperature (BT pre, r = 0.490, p = 0.046) and pre-exercise glucose levels (Glucose pre, r = 0.934, p = 0.000). Post-exercise left foot Jack's test (LJack post) correlated with pre-exercise heart rate (HR pre, r = 0.540, p = 0.025) and post-exercise blood oxygen saturation (BOS post, r = 0.520, p = 0.027). Post-exercise right foot Jack's test (RJack post) correlated with pre-exercise heart rate (HR pre, r = 0.489, p = 0.047), and post-exercise right foot navicular drop (RDrop post) correlated with post-exercise body temperature (BT post, r = 0.578, p = 0.012).

Table 2. Pre-post results of Super OCR (13 km).

	Pre	Post		Cohen's D	95% Confidence Interval			
Variable (UNIT)	**Mean ± SD**	**Mean ± SD**	**% Change**		**Inferior**	**Superior**	**T**	***p***
CMJ (m)	39.35 ± 4.73	36.79 ± 7.28	−6.51	−0.54	0.82	4.28	3.02	0.01
ABK (m)	47.24 ± 6.86	40.45 ± 11.23	−14.37	−0.99	3.16	10.42	3.83	0.00
CCA	7.9 ± 4.61	5.04 ± 5.73	−36.20	−0.62	0.75	4.98	2.77	0.01
FVC (mL)	5.76 ± 2.42	5.46 ± 2.17	−5.21	−0.12	−0.71	1.30	0.60	0.55
Fev1 (mL)	3.88 ± 0.65	3.37 ± 1.05	−13.14	−0.78	0.21	0.83	3.39	0.00
FEF25 (mL)	8.65 ± 2.52	8.22 ± 3.04	−4.97	−0.17	−0.47	1.31	0.97	0.34
HR (bpm)	83 ± 18.2	105 ± 15.92	26.51	1.21	−27.17	−16.83	−8.75	0.00
BOS (%)	96.37 ± 9.54	93.37 ± 17.14	−3.11	−0.31	−5.02	11.02	0.77	0.45
BT (°C)	35.12 ± 2.07	34.82 ± 2.32	−0.85	−0.14	−0.98	1.59	0.49	0.63
IHS (kg)	44.67 ± 12.55	42.52 ± 9.58	−4.81	−0.17	−1.15	5.45	1.34	0.19
Color (au)	3 ± 1.97	6.17 ± 0.92	105.67	1.61	−4.26	−2.07	−6.10	0.00
Ph	5.85 ± 0.75	5.35 ± 0.59	−8.55	−0.67	0.11	0.89	2.70	0.01
Protein (mg/dL)	0.25 ± 0.44	0.6 ± 0.5	140.00	0.80	−0.73	0.03	−1.93	0.07
Glucose (mg/dL)	0.15 ± 0.37	0.05 ± 0.22	−66.67	−0.27	−0.04	0.24	1.45	0.16
RPE	6 ± 0	13.5 ± 2.4		0.10	−8.47	−6.53	−15.91	0.00
Lac (mmol)	0.65 ± 0.22	5.29 ± 3.21		21.09	−5.91	−3.38	−7.56	0.00
LST	1.42 ± 0.81	1.85 ± 0.46		0.53	−0.75	−0.10	−2.67	0.01
RST	1.73 ± 0.67	2 ± 0		0.40	−0.54	0.00	−2.06	0.05
LFlex (°)	75.27 ± 10.66	76.04 ± 11.98		0.07	−5.67	4.13	−0.32	0.75
RFlex (°)	76.04 ± 14.35	79.96 ± 11.45		0.27	−8.46	0.61	−1.78	0.09
LDisk	0.73 ± 0.72	0.84 ± 0.83		0.15	−0.56	0.33	−0.53	0.60
RDisk	0.58 ± 0.7	0.81 ± 0.75		0.33	−0.63	0.17	−1.19	0.25
LJack	0.62 ± 0.5	0.46 ± 0.51		−0.32	−0.09	0.40	1.28	0.21
RJack	0.65 ± 0.49	0.46 ± 0.51		−0.39	−0.04	0.42	1.73	0.10
LDrop (cm)	0.67 ± 0.38	0.54 ± 0.32		−0.34	−0.03	0.29	1.73	0.10
RDrop (cm)	0.75 ± 0.33	0.57 ± 0.3		−0.55	0.03	0.31	2.56	0.02
CFFT (ms)	38.01 ± 11.38	36.72 ± 3.21		−0.11	−3.57	6.15	0.55	0.59

Countermovement jump (CMJ), Abalakov jump (ABK), coordinative and arm-using related capacities (CCA), forced vital capacity (FVC), Forced Espiratory Volume in the 1st second (Fev1), Forced Espiratory Flow between 25 and 75% of forced vital capacity (FEF25), heart rate (HR), blood oxygen saturation (BOS), body temperature (BT), isometric hand strength (IHS), rate of perceived exertion (RPE), lactate (Lac), left leg stability (LST), right leg stability (RST), left leg flexibility (LFlex), right leg flexibility (RFlex), left scapular dyskinesis (LDisk), right scapular dyskinesis (RDisk), left foot Jack's test (LJack), right foot Jack's test (RJack), left foot navicular drop (LDrop), right foot navicular drop (RDrop), critical flicker fusion threshold arousal (CFFT).

In the 5 km Sprint distance, the following negative bivariate correlations were found: Probe time negatively correlated with pre-exercise countermovement jump (CMJ pre, r = 0.823, p = 0.000), pre-exercise Abalakov jump (ABK pre, r = 0.784, p = 0.000), pre-exercise coordinative and arm-using capacities (CCA pre, r = 0.511, p = 0.015), and pre-exercise forced vital capacity (FVC pre, r = 0.431, p = 0.045). Pre-exercise forced expiratory volume in 1 s (Fev1 pre) correlated negatively with probe time (r = 0.565, p = 0.006), as did post-exercise CMJ (CMJ post, r = 0.821, p = 0.000), post-exercise ABK (ABK post, r = 0.702, p = 0.001), and post-exercise FVC (FVC post, r = 0.643, p = 0.004). Post-exercise Fev1 (Fev1 post, r = 0.649, p = 0.004), post-exercise forced expiratory flow between 25 and 75% (FEF25 post, r = 0.606, p = 0.008), pre-exercise body temperature (BT pre, r = 0.584, p = 0.005), and pre-exercise isometric hand strength (IHS pre, r = 0.801, p = 0.000) also showed negative correlations with probe time. Lactate post-exercise (Lac post) correlated negatively with probe time (r = 0.540, p = 0.025), as did post-exercise IHS (IHS post, r = 0.714, p = 0.001), change in pH (ΔpH, r = 0.655, p = 0.015), and body weight (BW, r = 0.640, p = 0.001). Additionally, height (r = 0.544, p = 0.007) and BMI (r = 0.519, p = 0.011) showed negative correlations with probe time.

Pre-exercise left foot navicular drop (LDrop pre) correlated negatively with post-exercise ABK (r = 0.507, p = 0.038) and post-exercise CCA (r = 0.713, p = 0.001). Pre-exercise right foot navicular drop (RDrop pre) correlated negatively with post-exercise CCA (r = 0.514, p = 0.035), while post-exercise RDrop (RDrop post) correlated negatively with pre-exercise glucose (r = 0.520, p = 0.039) and post-exercise CCA (r = 0.506, p = 0.038). Pre-exercise left leg flexibility (LFlex pre) correlated negatively with post-exercise pH (r = 0.702, p = 0.007), protein (r = 0.669, p = 0.012), and glucose (r = 0.735, p = 0.004), while pre-exercise right leg flexibility (RFlex pre) correlated negatively with post-exercise color (r = 0.569, p = 0.043), pH (r = 0.630, p = 0.021), and protein (r = 0.572, p = 0.041). Post-exercise LFlex correlated negatively with post-exercise protein (r = 0.554, p = 0.040) and pH (r = 0.579, p = 0.030). Post-exercise RFlex correlated negatively with post-exercise FVC (r = 0.509, p = 0.031).

Post-exercise rate of perceived exertion (RPE post) correlated negatively with pre-exercise left scapular dyskinesis (LDisk pre, r = 0.678, p = 0.003) and right scapular dyskinesis (RDisk pre, r = 0.688, p = 0.002). Pre-exercise left leg stability (LST pre) correlated negatively with post-exercise body temperature (BT post, r = 0.553, p = 0.021) and post-exercise glucose (r = 0.576, p = 0.039). Pre-exercise right leg stability (RST pre) also correlated negatively with post-exercise body temperature (BT post, r = 0.814, p = 0.000) and glucose (r = 0.576, p = 0.039). Pre-exercise left foot Jack's test (LJack pre) correlated negatively with post-exercise lactate (r = 0.604, p = 0.013) and critical flicker fusion threshold arousal (CFFT post, r = 0.670, p = 0.005). Similarly, pre-exercise right foot Jack's test (RJack pre) correlated negatively with post-exercise lactate (r = 0.604, p = 0.013) and CFFT post (r = 0.670, p = 0.005).

In the 13 km Super distance, several positive correlations were found. Pre-exercise left leg flexibility (LFlex pre) was positively correlated with the post-exercise rate of perceived exertion (RPE post, r = 0.436, p = 0.030). Pre-exercise right leg flexibility (RFlex pre) was positively correlated with post-exercise protein levels (Protein post, r = 0.424, p = 0.049). Pre-exercise right scapular dyskinesis (RDisk pre) showed a positive correlation with pre-exercise glucose levels (Glucose pre, r = 0.450, p = 0.010). Pre-exercise right foot Jack's test (RJack pre) was positively correlated with pre-exercise heart rate (HR pre, r = 0.498, p = 0.002). Pre-exercise left foot navicular drop (LDrop pre) showed positive correlations with post-exercise forced vital capacity (FVC post, r = 0.487, p = 0.009), pre-exercise glucose levels (Glucose pre, r = 0.463, p = 0.008), post-exercise glucose levels (Glucose post, r = 0.443, p = 0.039), and pre-exercise critical flicker fusion threshold arousal (CFFT pre, r = 0.484, p = 0.004). Pre-exercise right foot navicular drop (RDrop pre) was positively correlated with pre-exercise coordinative and arm-using capacities (CCA pre, r = 0.398, p = 0.015), pre-exercise forced expiratory volume in the first second (Fev1 pre, r = 0.337, p = 0.044), and post-exercise forced vital capacity (FVC post, r = 0.400, p = 0.035). Post-exercise left leg flexibility (LFlex post) showed positive correlations with pre-exercise blood oxygen saturation (BOS pre, r = 0.451, p = 0.024), pre-exercise pH (pH pre, r = 0.444, p = 0.038), and post-exercise rate of perceived exertion (RPE post, r = 0.452, p = 0.030). Post-exercise right leg flexibility (RFlex post) was positively correlated with pre-exercise blood oxygen saturation (BOS pre, r = 0.434, p = 0.030) and pre-exercise pH (pH pre, r = 0.499, p = 0.018). Post-exercise right scapular dyskinesis (RDisk post) was positively correlated with pre-exercise coordinative and arm-using capacities (CCA pre, r = 0.443, p = 0.021). Post-exercise left foot Jack's test (LJack post) showed positive correlations with pre-exercise heart rate (HR pre, r = 0.508, p = 0.010) and post-exercise heart rate (HR post, r = 0.600, p = 0.001). Post-exercise right foot Jack's test (RJack post) was positively correlated with post-exercise heart rate (HR post, r = 0.562, p = 0.002) and post-exercise protein levels (Protein post, r = 0.440, p = 0.046). Post-exercise left foot navicular drop (LDrop post) was positively correlated with post-exercise glucose levels (Glucose post, r = 0.628, p = 0.002) and pre-exercise critical flicker fusion threshold arousal (CFFT pre, r = 0.620, p = 0.001).

In the 13 km Super distance, the following negative bivariate correlations were found: Probe time negatively correlated with pre-exercise Abalakov jump (ABK pre, r = 0.418,

$p = 0.005$), pre-exercise coordinative and arm-using capacities (CCA pre, r = 0.363, $p = 0.017$), pre-exercise forced expiratory flow between 25 and 75% (FEF25 pre, r = 0.322, $p = 0.040$), and post-exercise countermovement jump (CMJ post, r = 0.598, $p = 0.001$). It also showed negative correlations with post-exercise Abalakov jump (ABK post, r = 0.661, $p = 0.000$), post-exercise forced vital capacity (FVC post, r = 0.436, $p = 0.018$), pre-exercise isometric hand strength (IHS pre, r = 0.398, $p = 0.012$), and post-exercise isometric hand strength (IHS post, r = 0.416, $p = 0.025$). Additionally, change in countermovement jump (ΔCMJ, r = 0.578, $p = 0.001$), change in pH (ΔpH, r = 0.492, $p = 0.027$), and height (r = 0.356, $p = 0.028$) were negatively correlated with probe time.

Pre-exercise left leg stability (LST pre) showed negative correlations with pre-exercise countermovement jump (CMJ pre, r = 0.394, $p = 0.016$), pre-exercise heart rate (HR pre, r = 0.345, $p = 0.043$), pre-exercise colour (Color pre, r = 0.402, $p = 0.028$), and post-exercise lactate (Lac post, r = 0.583, $p = 0.001$). Pre-exercise right leg stability (RST pre) negatively correlated with pre-exercise colour (Color pre, r = 0.371, $p = 0.044$), pre-exercise pH (pH pre, r = 0.545, $p = 0.001$), and pre-exercise protein levels (Protein pre, r = 0.484, $p = 0.005$). Pre-exercise left leg flexibility (LFlex pre) was negatively correlated with pre-exercise forced expiratory volume in the first second (Fev1 pre, r = 0.336, $p = 0.045$) and post-exercise critical flicker fusion threshold arousal (CFFT post, r = 0.422, $p = 0.025$).

Pre-exercise left scapular dyskinesis (LDisk pre) negatively correlated with post-exercise heart rate (HR post, r = 0.522, $p = 0.004$), and pre-exercise right scapular dyskinesis (RDisk pre) also showed a negative correlation with post-exercise heart rate (HR post, r = 0.447, $p = 0.017$). Pre-exercise left foot Jack's test (LJack pre) was negatively correlated with pre-exercise isometric hand strength (IHS pre, r = 0.342, $p = 0.044$) and post-exercise isometric hand strength (IHS post, r = 0.498, $p = 0.007$). Pre-exercise left foot navicular drop (LDrop pre) negatively correlated with pre-exercise countermovement jump (CMJ pre, r = 0.363, $p = 0.027$), and pre-exercise right foot navicular drop (RDrop pre) showed a negative correlation with pre-exercise blood oxygen saturation (BOS pre, r = 0.430, $p = 0.010$).

Post-exercise left leg stability (LST post) negatively correlated with pre-exercise protein levels (Protein pre, r = 0.463, $p = 0.030$) and post-exercise pH (pH post, r = 0.507, $p = 0.019$). Post-exercise left leg flexibility (LFlex post) showed negative correlations with pre-exercise Abalakov jump (ABK pre, r = 0.577, $p = 0.002$), pre-exercise coordinative and arm-using capacities (CCA pre, r = 0.593, $p = 0.001$), pre-exercise forced vital capacity (FVC pre, r = 0.476, $p = 0.014$), pre-exercise forced expiratory volume in the first second (Fev1 pre, r = 0.581, $p = 0.002$), pre-exercise forced expiratory flow between 25 and 75% (FEF25 pre, r = 0.466, $p = 0.016$), post-exercise forced expiratory volume in the first second (Fev1 post, r = 0.404, $p = 0.037$), post-exercise forced expiratory flow between 25 and 75% (FEF25 post, r = 0.466, $p = 0.014$), and post-exercise critical flicker fusion threshold arousal (CFFT post, r = 0.404, $p = 0.037$).

Post-exercise right leg flexibility (RFlex post) negatively correlated with pre-exercise coordinative and arm-using capacities (CCA pre, r = 0.474, $p = 0.013$), pre-exercise forced expiratory volume in the first second (Fev1 pre, r = 0.416, $p = 0.035$), and post-exercise forced vital capacity (FVC post, r = 0.548, $p = 0.003$). Post-exercise right foot Jack's test (RJack post) showed a negative correlation with pre-exercise body temperature (BT pre, r = 0.558, $p = 0.004$). Post-exercise left foot navicular drop (LDrop post) negatively correlated with pre-exercise countermovement jump (CMJ pre, r = 0.432, $p = 0.024$), and post-exercise right foot navicular drop (RDrop post) showed negative correlations with pre-exercise countermovement jump (CMJ pre, r = 0.505, $p = 0.007$), post-exercise countermovement jump (CMJ post, r = 0.425, $p = 0.027$), and pre-exercise isometric hand strength (IHS pre, r = 0.443, $p = 0.027$).

The post hoc correlation analysis conducted between pre- and post-race variables revealed several significant relationships. Notably, there was a strong positive correlation between pre- and post-race CMJ (r = 0.80) and ABK (r = 0.68) values, suggesting that athletes with higher pre-race explosive strength were able to maintain better performance levels after the race. This highlights the importance of initial strength capacity in preserving post-race performance, particularly in terms of leg power. Upper body coordination and grip strength, measured through CCUB, displayed weaker correlations between pre- and post-race values. This indicates that these measures may be more affected by race-induced fatigue or the specific demands of the obstacle course, making them less consistent across pre- and post-race conditions. In terms of respiratory function, FVC and Fev1 demonstrated moderate positive correlations between pre- and post-race values (r = 0.43 for FVC, r = 0.47 for Fev1). These results suggest that respiratory endurance remains relatively stable during the race but experience moderate reductions post-race, likely due to race-induced exertion and fatigue. Furthermore, the cross-variable correlations revealed that pre-race CMJ and ABK were moderately correlated with post-race respiratory measures, such as FVC and Fev1. This indicates that athletes with greater muscular performance might also exhibit better maintenance of respiratory capacity under race conditions, emphasizing the interconnectedness of muscular and respiratory endurance in overall race performance.

Finally, a linear regression analysis was performed to evaluate the relationship between pre-race physiological variables and post-race countermovement jump (CMJ) performance. The model explained 56% of the variance in post-race CMJ ($R^2 = 0.56$). The strongest positive predictors of post-race CMJ were pre-race CMJ ($\beta = 0.63$) and forced vital capacity (FVC) ($\beta = 0.34$). Conversely, pre-race upper-body coordination and grip strength (CCUB) had a negative impact ($\beta = -0.39$), suggesting that athletes with better pre-race lower-body explosive power and lung capacity tend to maintain better performance, while upper-body fatigue might contribute to reduced jump capacity post-race. Other pre-race variables, such as Abalakov jump (ABK) and FER25, showed smaller positive contributions, while Fev1 had a minor negative influence.

4. Discussion

In this study, we observed significant physiological responses to both the Sprint (5 km) and Super (13 km) obstacle course races (OCR). The decrease in leg strength was more pronounced in the Sprint race (Cohen's d = −0.56, $p < 0.01$) compared to the Super race (Cohen's d = −0.54, $p = 0.01$), suggesting that shorter, more intense efforts may lead to a more acute reduction in muscular power. This aligns with the anaerobic demands of the Sprint race, which require high-intensity exertion over a shorter duration, thus leading to rapid muscle fatigue. Similarly, the decline in urine pH was significant in both distances but slightly more pronounced in the Sprint (Cohen's d = −0.70, $p = 0.03$) compared to the Super race (Cohen's d = −0.67, $p = 0.01$). This indicates a greater accumulation of metabolic byproducts, such as hydrogen ions, during the shorter race, further emphasizing the intense anaerobic activity. The increase in blood lactate was substantial in both races, with a large effect size observed for both the Sprint (Cohen's d = 34.15, $p < 0.01$) and Super (Cohen's d = 21.09, $p < 0.01$). However, lactate accumulation was higher in the Sprint race, likely due to the more significant reliance on anaerobic energy pathways. This higher lactate concentration suggests that athletes in shorter races need greater lactate tolerance to sustain high performance over short bursts of activity.

Perceived exertion also increased significantly post-race, with similar effect sizes in both the Sprint (Cohen's d = 0.10, $p < 0.01$) and Super (Cohen's d = 0.10, $p < 0.01$) distances. This reflects the overall physical demands of the races, though it is worth noting that while the effect size for perceived exertion is similar, athletes in the longer Super race may have experienced more cumulative fatigue due to the extended duration of exertion. The comparison of these physiological responses between the Sprint and Super races underscores the differing demands of short versus long OCR events. Shorter races appear to elicit a greater reliance on anaerobic metabolism, leading to faster declines in strength and higher levels of lactate accumulation. In contrast, the Super race, while still physically demanding, places more emphasis on endurance and sustained effort, with a less pronounced immediate impact on certain physiological markers, such as leg strength and urine pH. These findings highlight the need for tailored training programs that address both anaerobic capacity for short-distance races and endurance for longer courses.

4.1. Physiological Responses to OCR

The study showed that both the 5 km and 13 km OCR significantly affected various physiological parameters. The observed decrease in leg strength and urine pH, coupled with increased blood lactate and perceived exertion, highlights the significant physiological demands of OCR events. The positive correlation between pre-race body temperature and performance, as well as post-race thermoregulation, underscores the importance of proper preparation for heat management in OCR athletes.

One of the main purposes of this study was to analyse the physiological response in OCR. We found a significant decrease in the leg's strength after the race in both Sprint and Super distances, supporting data from previous research in half-mountain marathons [32]. This fact may be related to the increase in metabolic demands that produce a higher anaerobic metabolism activation and then a higher blood lactate concentration, a fact related to a decrease in the ability to produce force [32,33]. In this line, both races presented a decrease in urine pH, as well as an increase in urine glucose, protein, and color, a fact that corresponds to intense exercise [34] and dehydration status [35]. In the Super distance, the Fev1 decreased after the race, probably because of the fatigue of the respiratory muscles, since it has been seen in the literature that both diaphragm and intercostal muscles involved in the breathing mechanics can be exhausted after extenuated aerobic exercise [36]. Regarding the injury tests, we observed that lower limb stability in a single leg stance decreased after the long course in both feet, a fact in which fatigue has a direct impact [37]. Contradictory evidence exists in this area since previous studies postulated that these changes occur because of neuromuscular failure at the ankle complex prior to hip muscles [38]. Others demonstrated that hip muscles are responsible for the lack of stability due to fatigue [39]. The stability or instability of the lower limbs may depend on the physical conditioning of the athlete, with either ankle or hip joints potentially being responsible.

In the Sprint distance, participants with lower pre-race heart rates achieved better performance, showing the importance of cardiovascular fitness in this OCR distance. Also, the higher pre-body temperature and the post-lower body temperature were correlated with probe time, demonstrating the relationship between good thermoregulatory capacities and performance in OCR. In this line, the first participants to cross the finish line had higher blood lactate concentrations, and lactate tolerance was presented as an important key factor in OCR performance. The urine ΔpH is also an indicator of exercise intensity, and we found that faster athletes presented a higher decrease in pH, a fact that also supports the idea that a better workout capacity in an acidic environment provides better performance. In both distances, higher values in isometric handgrip strength pre- and post-exercise correlate with performance. Specific grip muscle training, as well as climbing training for suspension obstacles, would improve OCR performance. In this line, participants with higher pre-leg strength also achieved higher performance in both distances, supporting previous research in which plyometric training improved both jump height and running performance because of the improvements in running economy and muscle and tendon stiffness factors [40]. In the Sprint distance, post measurements of leg strength correlated negatively with probe time, but in the Super distance, this correlation was positive. We could explain this phenomenon since, in a long course, dehydration and neuromuscular fatigue are higher because of the time required to complete the race [41]. In both courses, spirometry values pre- and post-race presented a large positive correlation with performance, which supports previous evidence showing the relationship between selected lung capacities and performance in running performance [42]. In this line, it could be interesting to design specific respiratory muscle training programs to improve these capacities. Finally, related to height and body weight, higher and heavier participants in Sprint distance and higher ones in Super distance correlated positively with performance. This fact is contrary to other findings in endurance running, so it probably has a relation with the obstacles passing. Future research in OCR will have to support this evidence.

The results demonstrate that participants with lower pre-race heart rates achieved better performance in the Sprint distance, highlighting the importance of cardiovascular fitness for shorter OCR events. Additionally, participants with higher pre-race body temperatures and lower post-race body temperatures had faster completion times, indicating that efficient thermoregulation plays a crucial role in performance. Furthermore, higher blood lactate concentrations in the fastest participants underscore the significance of lactate tolerance as a key factor for success in OCR. This suggests that athletes capable of maintaining performance under high lactate levels demonstrate better race outcomes. In particular, grip strength showed a strong positive correlation with performance in both distances (Sprint: $r = 0.71$, $p = 0.001$; Super: $r = 0.72$, $p = 0.01$), indicating the importance of upper body strength for overcoming obstacles. Specific grip and suspension training would likely benefit OCR athletes by enhancing performance in these high-demand activities.

4.2. Injury Risk and Prevention

Injury risk was a critical focus of this study, with significant findings related to lower limb stability and foot biomechanics. The decrease in lower limb stability post-race, particularly in single-leg standing tests, indicates an increased risk of ankle and knee injuries due to neuromuscular fatigue. Additionally, reduced foot biomechanics, as measured by navicular drop and Jack's test, points to a higher likelihood of overuse injuries such as plantar fasciitis and Achilles tendinopathy. These results emphasize the need for targeted interventions to improve stability and foot mechanics in OCR training programs to reduce injury risk.

One of the most important characteristics of obstacle races is the high technical demands of some obstacles, which directly affect the risk of various injuries, such as ankle and knee sprains, because of the abrupt terrain of the courses [43]; shoulder sprains, dislocations, and subluxations [44]; superior labrum antero-posterior (SLAP) fractures; rotator cuff and other shoulder muscle tears; epicondylus lateralis and medialis tendinopathies; hand–wrist complex tendons and ligaments tears [17]; and lower and upper body traumas caused by falls and other overstrain injuries caused by performing hard moves in suspension obstacles [45]. Thus, it is important to present high muscular strength and stability in order to minimize injury risks [15]. We observed that participants with greater windlass mechanism prior to the race could generate a higher exercise intensity since their blood lactate concentration was higher, and they had greater cortical arousal values in the Sprint distance and higher heart rate after the race in the Super distance. But, this biomechanical pattern is also important for avoiding injuries because it can be affected by alterations in mobility. For example, hypermobility of the first radial chain of the foot develops a restrain of mobility in the first metatarsophalangeal joint, and it alters the position of the foot during the propulsive phase of the run and gait, so the subtalar joint must compensate by pronating the foot [13]. This causes the incapacity of the peroneus longi to stabilize the first radius, and thus, it loses its mechanical advantage. Repeated efforts with this altered pattern can cause femoropatellar pain syndrome [46], stress fractures, medial tibial stress, plantar fasciopathies, aquiles tendinopathies, and muscular strains [13,47]. In this research, subjects with greater windlass mechanism post probe showed lower heart rate pre. With this information, we can affirm that it is imperative to have good cardiovascular conditioning to mitigate exercise-dependent fatigue and avoid injuries [48]. It is also important to remark that an excessive navicular drop, added to a high training volume, can also cause anterior cruciate ligament pathologies, in addition to the injuries already mentioned, which were derived from a poor windlass pattern [49]. In this study, navicular drop prior to and post-race was correlated negatively with leg explosive strength and coordination and the use of arms capacities before and after the probe in both distances. We found a positive relationship between foot stability and isometric handgrip strength, but we did not find any evidence in the literature to support these data. We believe that the more conditioned the athlete is, the greater the values in strength and stability overall. The one-leg standing test pre correlated positively with the CMJ pre, presenting higher jump values and greater stability. This supports actual evidence where a relationship between balance and jumping performance has been found [50]. The author of this review analyses the scientific literature to understand the mechanisms of balance training in athletic performance, finding consistent data in improvements of the rate of force development (RFD), inhibitions of muscle stretch reflexes, increases in muscular stiffness, and decreases in the amortization phase of stretch-shortening cycle [50]. Additionally, leg stability correlated well with post-race blood lactate concentration, supporting data from this research in which stability and the ability to perform at high intensities were found. We also observed that participants with better shoulder cinematics before the race showed higher values of rate of perceived exertion in the Sprint distance and higher heart rate after the Super distance. Then, better stability and biomechanics have the possibility to perform higher intensities. Hamstring flexibility is negatively correlated with jump height. This phenomenon could be explained by lower limb stiffness, which is one of the most important factors in jumping and running performance [51]. Optimal levels of stiffness are important for avoiding injuries [51], but it has also been seen in the literature that runners with greater hamstring flexibility are less susceptible to injuries [47]. Minimum hamstring flexibility is required, but in excess, it can be counterproductive to improve performance and intra and inter-muscular coordination [51].

Our results indicate a significant decrease in lower limb stability post-race in both the Sprint and Super distances, highlighting a heightened risk of injury due to neuromuscular fatigue. This reduction in stability, measured through single-leg standing tests, serves as a key indicator of vulnerability to ankle and knee sprains, as well as other injuries stemming from altered biomechanics during the race. Specifically, participants with lower pre- and post-race stability scores showed higher correlations with longer completion times and increased perceived exertion, emphasizing the importance of stability in both performance and injury prevention.

Furthermore, the observed decrease in foot biomechanics, as indicated by changes in the navicular drop test and Jack's test, suggests that foot stability is a critical component in mitigating injury risk. Participants with greater foot instability demonstrated a higher likelihood of compensatory movement patterns, which may lead to overuse injuries such as plantar fasciitis or Achilles tendinopathy. The unique data collected in this study underscores the importance of incorporating specific lower limb stability and foot biomechanics training into OCR preparation programs. By improving these factors, athletes can reduce the risk of injury, particularly in high-demand activities involving uneven terrain and repeated impact, which are common in OCR events. This evidence provides a strong rationale for trainers and health professionals to prioritize injury prevention strategies that target neuromuscular control and stability, particularly in the lower limbs.

4.3. Practical Applications

Given the information above, it would be interesting to include respiratory muscle training in the athletes' plans due to its relationship with performance. Grip strength training is required to improve performance and reduce the injury risk. Leg explosive strength showed great negative correlations with probe time and risk of injury, so to improve this capacity, training programs should include maximum strength and plyometrics sessions. Energy systems improvement should be taken into consideration when designing training plans since athletes with the ability to withstand higher blood lactate concentrations were able to run faster. Poor values of lower limb stability were obtained in both pre- and post-race measurements, but they were even worse after the race, so practitioners must keep this in mind in their interventions due to its relationship with injury risks and energetic output. In this line, nutritional support [52,53], psychological interventions [54,55], and functional neurology [56,57] sessions would be beneficial actions for OCR athletes.

4.4. Limitations of the Study

Analysing stress-related hormones such as cortisol and other biomarkers of muscular damage such as creatine kinase would improve knowledge about the impact of these probes on participants' organisms. A larger number of participants would improve statistical analysis, but human and economic resources limited it. Finally, a larger number of women would lead us to better understand possible differences between the sexes.

5. Conclusions

We can conclude that a short OCR causes a higher activation of lactic anaerobic pathways, and the long course has more impact on the hydration status. Leg explosive strength and stability decrease after both OCRs. Spirometry values, lactate concentration, and leg and handgrip strength positively correlated with OCR performance.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14209604/s1, Table S1: Bivariate positive correlations in Sprint distance (5 km); Table S2: Bivariate negative correlations in Sprint distance (5 km); Table S3: Bivariate positive correlations in Super distance (13 km); Table S4: Bivariate negative correlations in Super distance (13 km).

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References

1. Rawdon, C.L. Performance variables of obstacle course racing and recommendations for programming in novice and intermediate competitors. *Strength Cond. J.* **2016**, *38*, 1–17. [CrossRef]
2. Joyner, M.J.; Coyle, E.F. Endurance exercise performance: The physiology of champions. *J. Physiol.* **2008**, *586*, 35–44. [CrossRef] [PubMed]
3. Frykman, P.; Harman, E.; Pandorf, C. *Correlates of Obstacle Course Performance Among Female Soldiers Carrying Two Different Loads*; Army Research Institute of Environmental Medicine, Defense Technical Information Center: Natick, MA, USA, 2001; Volume 18, pp. 179–189.
4. Jones, R.M.; Cook, C.C.; Kilduff, L.P.; Milanović, Z.; James, N.; Sporiš, G.; Fiorentini, B.; Fiorentini, F.; Turner, A.; Vučković, G. Relationship between repeated sprint ability and aerobic capacity in professional soccer players. *ScientificWorldJournal* **2013**, *2013*, 952350. [CrossRef] [PubMed]
5. Millet, G.P.; Vleck, V.E.; Bentley, D.J. Physiological differences between cycling and running. *Sports Med.* **2009**, *39*, 179–206. [CrossRef]
6. Santos-Concejero, J.; Oliván, J.; Maté-Muñoz, J.L.; Muniesa, C.; Montil, M.; Tucker, R.; Lucia, A. Gait-cycle characteristics and running economy in elite Eritrean and European runners. *Int. J. Sports Physiol. Perform.* **2015**, *10*, 381–387. [CrossRef]
7. Tomporowski, P.D. Effects of acute bouts of exercise on cognition. *Acta Psychol.* **2003**, *112*, 297–324. [CrossRef]
8. Mrakic-Sposta, S.; Gussoni, M.; Moretti, S.; Pratali, L.; Giardini, G.; Tacchini, P.; Dellanoce, C.; Tonacci, A.; Mastorci, F.; Borghini, A.; et al. Effects of mountain ultra-marathon running on ROS production and oxidative damage by micro-invasive analytic techniques. *PLoS ONE* **2015**, *10*, e0141780. [CrossRef]
9. Greenberg, M.R.; Kim, P.H.; Duprey, R.T.; Jayant, D.A.; Steinweg, B.H.; Preiss, B.R.; Barr, G.C. Unique obstacle race injuries at an extreme sports event: A case series. *Ann. Emerg. Med.* **2014**, *63*, 361–366. [CrossRef]

10. Taunton, J.E.; Ryan, M.B.; Clement, D.B.; McKenzie, D.C.; Lloyd-Smith, D.R.; Zumbo, B.D. A prospective study of running injuries: The Vancouver Sun Run "In Training" clinics. *Br. J. Sports Med.* **2003**, *37*, 239–244. [CrossRef]
11. Emery, C. Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. *J. Sci. Med. Sport* **2003**, *6*, 492–504. [CrossRef]
12. Sell, K.E.; Verity, T.M.; Worrell, T.W.; Pease, B.J.; Wigglesworth, J. Two measurement techniques for assessing subtalar joint position: A reliability study. *J. Orthop. Sports Phys. Ther.* **1994**, *19*, 162–167. [CrossRef] [PubMed]
13. Munuera, P.V.; Trujillo, P.; Güiza, I. Hallux interphalangeal joint range of motion in feet with and without limited first metatarsophalangeal joint dorsiflexion. *J. Am. Podiatr. Med. Assoc.* **2012**, *102*, 47–53.
14. Cameron, D.M.; Bohannon, R.W. Relationship between active knee extension and active straight leg raise test measurements. *J. Orthop. Sports Phys. Ther.* **1993**, *17*, 257–260. [CrossRef] [PubMed]
15. Kibler, W.B.; Ludewig, P.M.; McClure, P.W.; Michener, L.A.; Bak, K.; Sciascia, A.D. Clinical implications of scapular dyskinesis in shoulder injury: The 2013 consensus statement from the 'Scapular Summit'. *Br. J. Sports Med.* **2013**, *47*, 877–885. [CrossRef] [PubMed]
16. Horsley, I.; Herrington, L.; Hoyle, R.; Prescott, E.; Bellamy, N. Do changes in hand grip strength correlate with shoulder rotator cuff function? *Shoulder Elb.* **2016**, *8*, 124–129. [CrossRef]
17. Schweizer, A. Sport climbing from a medical point of view. *Swiss. Med. Wkly.* **2012**, *142*, w13688. [CrossRef]
18. Suárez, V.J.C.; Muñoz, V.E.; Martínez, A. Fatiga del sistema nervioso después de realizar un test de capacidad de sprints repetidos (RSA) en jugadores de fútbol de categoría juvenil. *Apunts. Med. L'esport* **2011**, *46*, 177–182. [CrossRef]
19. Clemente-Suarez, V.J.; Palomera, P.R.; Robles-Pérez, J.J. Psychophysiological response to acute-high-stress combat situations in professional soldiers. *Stress Health* **2018**, *34*, 247–252. [CrossRef]
20. Hormeño-Holgado, A.J.; Clemente-Suárez, V.J. Effect of different combat jet manoeuvres in the psychophysiological response of professional pilots. *Physiol. Behav.* **2019**, *208*, 112559. [CrossRef]
21. Hormeño-Holgado, A.J.; Clemente-Suárez, V.J. Psychophysiological monitorization in a special operation selection course. *J. Med. Syst.* **2019**, *43*, 47. [CrossRef]
22. Hormeño-Holgado, A.J.; Perez-Martinez, M.A.; Clemente-Suárez, V.J. Psychophysiological response of air mobile protection teams in an air accident manoeuvre. *Physiol. Behav.* **2019**, *199*, 79–83. [CrossRef] [PubMed]
23. Suarez, V.C.; Campo, D.R.; Gonzalez-Rave, J.M. Modifications to body composition after running an alpine marathon: Brief clinical report. *Int. Sport. J.* **2011**, *12*, 133–140.
24. Clemente-Suárez, V.J.; Robles-Pérez, J.J. Psycho-physiological response of soldiers in urban combat. *An. Psicol.* **2013**, *29*, 598–603.
25. Clemente-Suárez, V.; González-Ravé, J.; Navarro-Valdivielso, F. Short-term periodized aerobic training does not attenuate strength capacity or jump performance in recreational endurance athletes. *Acta Physiol. Hung.* **2014**, *101*, 185–196. [CrossRef]
26. Sánchez-Molina, J.; Robles-Pérez, J.J.; Clemente-Suárez, V.J. Assessment of psychophysiological response and specific fine motor skills in combat units. *J. Med. Syst.* **2018**, *42*, 67. [CrossRef]
27. Tornero-Aguilera, J.F.; Robles-Pérez, J.J.; Clemente-Suárez, V.J. Effect of combat stress in the psychophysiological response of elite and non-elite soldiers. *J. Med. Syst.* **2017**, *41*, 1–6. [CrossRef]
28. Suarez, V.C.; Valdivielso, F.N.; Rave, J.M.G. Changes in biochemical parameters after a 20-hour ultra-endurance kayak and cycling event: Original research article. *Int. Sport. J.* **2011**, *12*, 1–6.
29. Harvey, G.; Meir, R.; Brooks, L.; Holloway, K. The use of body mass changes as a practical measure of dehydration in team sports. *J. Sci. Med. Sport* **2008**, *11*, 600–603. [CrossRef]
30. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand. J. Rehabil. Med.* **1970**, *2*, 92–98. [CrossRef]
31. Clemente-Suárez, V. Efecto sobre variables espirométricas basales de tres programas para el desarrollo de la resistencia aeróbica de 4 semanas de duración en atletas. *J. Sport Health Res.* **2013**, *5*, 211–220.
32. Rousanoglou, E.N.; Noutsos, K.; Pappas, A.; Bogdanis, G.; Vagenas, G.; Bayios, A.I.; Boudolos, K.D. Alterations of Vertical Jump Mechanics after a Half-Marathon Mountain Running Race. *J. Sports Sci. Med.* **2016**, *15*, 277–286. [PubMed]
33. Grassi, B.; Rossiter, H.B.; Zoladz, J.A. Skeletal muscle fatigue and decreased efficiency: Two sides of the same coin? *Exerc. Sport Sci. Rev.* **2015**, *43*, 75–83. [CrossRef] [PubMed]
34. Manzanares, J. Interpretation of basic urinalysis in athletes. *Semergen* **2015**, *41*, 387–390. [CrossRef] [PubMed]
35. Armstrong, L.E.; Herrera Soto, J.A.; Hacker Jr., F.T.; Casa, D.J.; Kavouras, S.A.; Maresh, C.M. Urinary indices during dehydration, exercise, and rehydration. *Int. J. Sport Nutr.* **1998**, *8*, 345–355. [CrossRef] [PubMed]
36. Perret, C.; Spengler, C.; Egger, G.; Boutellier, U. Influence of endurance exercise on respiratory muscle performance. *Med. Sci. Sports Exerc.* **2000**, *32*, 2052–2058. [CrossRef]
37. Springer, B.K.; Pincivero, D.M. The effects of localized muscle and whole-body fatigue on single-leg balance between healthy men and women. *Gait Posture* **2009**, *30*, 50–54. [CrossRef]
38. Riemann, B.L.; Myers, J.B.; Lephart, S.M. Comparison of the ankle, knee, hip, and trunk corrective action shown during single-leg stance on firm, foam, and multiaxial surfaces. *Arch. Phys. Med. Rehabil.* **2003**, *84*, 90–95. [CrossRef]
39. Gribble, P.; Hertel, J. Effect of hip and ankle muscle fatigue on unipedal postural control. *J. Electromyogr. Kinesiol.* **2004**, *14*, 641–646. [CrossRef]
40. Spurrs, R.W.; Murphy, A.J.; Watsford, M.L. The effect of plyometric training on distance running performance. *Eur. J. Appl. Physiol.* **2003**, *89*, 1–7. [CrossRef]

41. Judelson, D.A.; Maresh, C.M.; Anderson, J.M.; Armstrong, E.L.; Casa, D.J.; Kraemer, W.J.; Volek, J.S. Hydration and muscular performance. *Sports Med.* **2007**, *37*, 907–921. [CrossRef]
42. Pringle, E.; Latin, R.; Berg, K. The relationship between 10 km running performance and pulmonary function. *J. Exerc. Physiol.* **2005**, *8*, 22–28.
43. Lopes, A.D.; Hespanhol, L.C.; Yeung, S.S.; Costa, L.O.P. What are the main running-related musculoskeletal injuries? A systematic review. *Sports Med.* **2012**, *42*, 891–905. [CrossRef] [PubMed]
44. Owens, B.D.; Duffey, M.L.; Nelson, B.J.; DeBerardino, T.M.; Taylor, D.C.; Mountcastle, S.B. The incidence and characteristics of shoulder instability at the United States Military Academy. *Am. J. Sports Med.* **2007**, *35*, 1168–1173. [CrossRef] [PubMed]
45. Schoffl, V.; Morrison, A.; Schoffl, I.; Kupper, T. The epidemiology of injury in mountaineering, rock and ice climbing. *Med. Sport Sci.* **2012**, *58*, 17–43.
46. Wiegerinck, J.I.; Boyd, J.; Yoder, J.C.; Abbey, A.N.; Nunley, J.A.; Queen, R.M. Differences in plantar loading between training shoes and racing flats at a self-selected running speed. *Gait Posture* **2009**, *29*, 514–519. [CrossRef]
47. Hreljac, A.; Marshall, R.N.; Hume, P.A. Evaluation of lower extremity overuse injury potential in runners. *Med. Sci. Sports Exerc.* **2000**, *32*, 1635–1641. [CrossRef]
48. Gefen, A. Biomechanical analysis of fatigue-related foot injury mechanisms in athletes and recruits during intensive marching. *Med. Biol. Eng. Comput* **2002**, *40*, 302–310. [CrossRef]
49. Vinicombe, A.; Raspovic, A.; Menz, H.B. Reliability of navicular displacement measurement as a clinical indicator of foot posture. *J. Am. Podiatr. Med. Assoc.* **2001**, *91*, 262–268. [CrossRef]
50. Hrysomallis, C. Balance ability and athletic performance. *Sports Med.* **2011**, *41*, 221–232. [CrossRef]
51. Brazier, J.; Bishop, C.; Simons, C.; Antrobus, M.; Read, P.J.; Turner, A.N. Lower extremity stiffness: Effects on performance and injury and implications for training. *Strength Cond. J.* **2014**, *36*, 103–112. [CrossRef]
52. Clemente-Suárez, V.J.; Peris-Ramos, H.C.; Redondo-Flórez, L.; Beltrán-Velasco, A.I.; Martín-Rodríguez, A.; David-Fernandez, S.; Yáñez-Sepúlveda, R.; Tornero-Aguilera, J.F. Personalizing Nutrition Strategies: Bridging Research and Public Health. *J. Pers. Med.* **2024**, *14*, 305. [CrossRef] [PubMed]
53. Jimenez-Morcillo, J.; Clemente-Suárez, V.J. Gender Differences in Body Satisfaction Perception: The Role of Nutritional Habits, Psychological Traits, and Physical Activity in a Strength-Training Population. *Nutrients* **2024**, *16*, 104. [CrossRef] [PubMed]
54. Belinchón-deMiguel, P.; Ramos-Campo, D.J.; Clemente-Suárez, V.J. Exploring the Evolutionary Disparities: A Case Study on the Psychophysiological Response to Recreating the Hunter–Gatherer Lifestyle through Physical Activity and Caloric Restriction. *Appl. Sci.* **2023**, *13*, 11140. [CrossRef]
55. Martín-Rodríguez, A.; Gostian-Ropotin, L.A.; Beltrán-Velasco, A.I.; Belando-Pedreño, N.; Simón, J.A.; López-Mora, C.; Navarro-Jiménez, E.; Tornero-Aguilera, J.F.; Clemente-Suárez, V.J. Sporting Mind: The Interplay of Physical Activity and Psychological Health. *Sports* **2024**, *12*, 37. [CrossRef] [PubMed]
56. Rey-Mota, J.; Escribano-Colmena, G.; Fernandez-Lucas, J.; Parraça, J.A.; Clemente-Suárez, V.J. Impact of Professional Experience on Clinical Judgment and Muscular Response in Various Neuromuscular Tests. *Physiol. Behav.* **2024**, *283*, 114602. [CrossRef]
57. Rey-Mota, J.; Escribano-Colmena, G.; Álvarez, D.M.-C.; Vasquez Perez, J.; Navarro-Jimenez, E.; Clemente-Suárez, V.J. Application of Functional Neurology Therapy in a Lactose-Intolerant Patient. *Life* **2024**, *14*, 978. [CrossRef]