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Analysis of the Physiological Characteristics of Elite Male and Female Junior Rowers During Extreme Exercise

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Abstract

Background: Rowing is a highly demanding endurance sport, requiring simultaneous work of approximately 70% of the body's muscle mass and the combined contribution of aerobic and anaerobic energy systems. **Objective:** This study aimed to analyze the cardiorespiratory responses and performance characteristics of elite junior male and female rowers during maximal effort over 2000 m on a rowing ergometer. **Methods:** Fifteen junior rowers (six males aged 15–17 and nine females aged 15–18) participated in the study. Anthropometric data (body height, weight, and body surface area) were recorded. All participants performed a maximal 2000 m test on a Concept2 D-model ergometer. Throughout the test, oxygen uptake (VO_2), carbon dioxide production (VCO_2), heart rate, and ventilation parameters were continuously measured. Performance and physiological data were analyzed in three intensity zones, defined by ventilatory thresholds (VT1–VT3), as well as at peak exercise. **Results:** Significant anthropometric differences were observed between genders. In terms of performance, males completed the 2000 m test significantly faster than females (208.83 ± 87.66 s vs. 333.78 ± 97.51 s, $p = 0.0253$). Relative VO_2 at peak exercise was higher in males (58.73 ± 5.25 mL·kg^{-1}·min^{-1}) than females (48.32 ± 6.09 mL·kg^{-1}·min^{-1}, $p = 0.0046$). In most cardiorespiratory parameters, males outperformed females significantly, except for heart rate and ventilatory equivalents. Ranking analysis revealed that higher VO_2max values were generally associated with a better placement in both genders, though this relationship was not perfectly linear. Performance time was negatively correlated with VO_2Peak ($r = -0.8286$; $p < 0.001$), rVO_2Peak ($r = -0.6781$; $p < 0.01$), and O_2P_{Peak} ($r = -0.7729$; $p < 0.01$). **Conclusions:** The findings confirm significant gender differences in anthropometric and cardiorespiratory characteristics of elite junior rowers and reinforce VO_2max as a key determinant of performance. Yet, deviations from a direct VO_2max–rank correlation highlight the influence of tactical, psychological, and biomechanical factors. Future research should provide practical recommendations for monitoring performance and tailoring training to optimize adaptation and long-term athlete development.

Keywords: cardiorespiratory system; junior rowers; rowing physiology

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1. Introduction

Rowing is a competitive sport in which men and women of all ages participate. The goal of the standard competition is to propel the boat forward over a distance of 2000 m,

which can usually be completed in ~6–8 min [1]. Approximately 70% of the body's muscles are involved in combined static and dynamic work for 5.5–8 min, with an average power output of ~450–550 W [2]. The physiological basis of performance in 2000 m rowing is complex: although the race is primarily aerobic, glycolytic and alactic anaerobic components also contribute significantly to performance; according to various methods, the relative contribution is generally ~70–80% aerobic and ~20–30% anaerobic [2–5]. In recent decades, rowing ergometers have become the most widely used devices for simulating and evaluating rowing performance [3]. The ergometer provides an indoor, controlled environment that reproduces the movement pattern of rowing on water. It is an excellent tool for laboratory observation: (1) it provides a standardized and reproducible setting, (2) it closely approximates the kinematics of rowing and cardiorespiratory responses, and (3) it allows for precise control of external load [6,7]. Nevertheless, due to the specific characteristics of the aquatic environment (resistance conditions), the synchronization of the boat and crew, and tactical-psychological requirements, differences may remain between ergometer and on-water performance; therefore, caution is needed when externally validating ergometer results with results achieved on the water [2,8]. Boat speed is closely related to relative maximum oxygen uptake (rVO_2max), which typically reaches 65–70 mL·kg^{-1}·min^{-1} in elite junior rowing, as well as to VO_2max during competition [2]. Numerous studies have identified VO_2max as one of the most reliable predictors of rowing performance in male rowers [9–13]. Although VO_2max is often the strongest single predictor, performance is multidimensional: efficiency/economy (oxygen consumption required for a given mechanical work), respiratory/threshold parameters, neuromuscular capacity, and mechanical/technical efficiency all contribute significantly to the 2000 m result [2,4,11,14]. Maximum oxygen uptake (VO_2max) is a physiological characteristic determined by the parameters of Fick's equation: (left ventricular (LV) end-diastolic volume (LV end-systolic volume) x heart rate x arterial-venous oxygen difference. When interpreting VO_2max, it is important to emphasize its critical dependence on the oxygen transport capacity of the working skeletal muscles and the limitations that arise from this [15]. Recent studies have shown that upper-body strength and endurance contribute significantly to sex differences in aerobic power and performance when normalized to lean body mass [16,17]. In young athletes, the dynamics of biological maturation deserve special attention: increases in fat-free mass and hemoglobin mass, as well as hormonal changes during puberty, promote increases in VO_2max and endurance; early maturation often confers a performance advantage [18,19]. In terms of gender differences, boys/men generally show higher absolute—and in many cases higher relative—VO_2max values, while girls/women may show more favorable fractional utilization in submaximal ranges and/or different respiratory threshold profiles, which partially compensates for differences in absolute capacity [20]. Recent studies have demonstrated that male and female rowers differ significantly in VO_2 uptake and metabolic responses across intensity domains, with males showing higher aerobic power, ventilation, and oxygen uptake values even when accounting for body mass and weight category [15,21]. Moreover, in youth athletes, differences in maximal aerobic power and strength–largely attributable to sex and body composition–contribute meaningfully to performance disparities [16]. Overall, the state of maturation, gender-related characteristics, and technical-tactical development together shape the performance profile of elite junior rowers. Based on these considerations, the present study aimed to analyze the cardiorespiratory and performance indicators of elite junior male and female rowers during extreme exertion (2000 m ergometer), with a particular focus on comparing respiratory thresholds (VT1–VT3) and maximum workload. It also aimed to examine the relationships between gender, ranking, and physiological determinants [3,4,14]. An extreme physiological reaction is the body's intense response to

performing a perceived high-intensity task. Such a load typically lasts for a relatively short duration, during which heart rate approaches—and in many cases reaches—its maximum level, while the metabolic background shifts toward anaerobic metabolism.

2. Materials and Methods

This cross-sectional study included fifteen rowers (six men and nine women) who participated in the 2024 Hungarian Rowing Championships (July) and performed a 2000 m rowing performance test on a rowing ergometer at the Human Performance Laboratory in Győr, Hungary. The men were aged 15–17 years, with an average of six years of training experience. The women were aged 15–18 years, with an average of three years of training experience. All subjects were highly ranked in the Hungarian Rowing Federation rankings and had finished in the top positions in national rowing competitions. Only athletes belonging to the national elite group of their age category were included, while those who had suffered from illness or injury within the month prior to testing and were unable to complete regular training were excluded. The 2000 m rowing times achieved at the Hungarian Junior Rowing Championships were taken into account.

Data collection was conducted in full compliance with the ethical principles of the Declaration of Helsinki. Participants and their legal guardians were fully informed about the study and gave their written consent to participate. The study was conducted on a voluntary basis in cooperation with the sports clubs and national rowing associations involved. The study was conducted in accordance with the guidelines and regulations of the Scientific and Research Ethics Committee of Széchenyi István University (SZE/ETT-46/2025) and the Declaration of Helsinki.

We measured height (BH) and weight (BW), calculated body mass index (BMI) and body surface area (BSA). BMI is the ratio of body weight in kilograms to the square of body height in meters (kg/m2). BSA = 0.007184, * Height0.725, * Weight0.425 based on Du Bois methods. We recorded resting heart rate (HR) and maximum heart rate (MP) using a chest transmitter and receiver (Garmin HRM3-SS Garmin Ltd., Olathe, KS, USA).

Each subject was given the task of completing the 2000 m rowing distance as quickly as possible. In the laboratory, rowing was performed using a rowing ergometer, which indicates the power, rhythm, and time required to complete 2000 m. The rowing ergometer was calibrated, and the time required to complete 2000 m was recorded using a Concept 2 D model rowing machine (Morrisville, VT, USA). During the task, oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured using indirect calorimetry (JAEGER® Vyntus CPX), ISO 13485, Aartselaar, Belgium. In addition, heart rate was monitored using a Polar heart rate monitor (H7) with Bluetooth smart technology. The device was attached to the front of each participant's chest with an adjustable neoprene strap 60 s before the start of the race. The device automatically connected to its software (SentrySuite version 2.00, JAEGER® Vyntus CPX). It continuously recorded the test subject's heart rate data before, during, and after the test. We measure the amount of inhaled air with a gas analyzer attached to the treadmill, or in our case, the rowing ergometer, and use this to derive the characteristics of the circulatory, respiratory, and metabolic systems. A mask attached to the face and a mouthpiece attached to it are connected to the gas analyzer and equipped with sensors. The air sucked in from the space is separated so that oxygen (O_2) uptake and carbon dioxide (CO_2) release can be measured. More specifically, we compare the performance of the respiratory and circulatory systems with oxygen uptake (VO_2). In our laboratory, the computer uses the Haldane transformation and the Fick equation for the calculation. During exercise, we can monitor heart rate (HR), oxygenpulse (O_2P), tidal volume (Vt), respiratory rate (Bf), and changes in absolute (VO_2) and relative oxygen uptake (rVO_2) depending on exercise intensity. We also examine the metabolic background

RER = (VCO_2/VO_2), which is calculated as the ratio of the two gas fractions. We can also calculate the efficiency of oxygen and carbon dioxide utilization (VE/VO_2); (VE/VCO_2) by the ratio of air turned over per minute and oxygen used.

Statistical Analysis

The demographic and cardiorespiratory characteristics were compared by gender using a one-sample *t*-test. The *p*-value was set at 0.05 percentage points. The relationship between relative aerobic capacity (rVO_2max) and respiratory exchange ratios (RER_{peak}) selected based on rankings was illustrated in the form of Big plots. Pearson's correlation analysis was applied to examine relationships between absolute and relative aerobic capacity (VO_2max; rVO_2max), oxygenpulse (O_2P_{peak}) and performance ($Time_{peak}$) outputs.

Intensity zones were defined based on respiratory breakpoints (VT_1, VT_2, VT_3), Peak of exercise (Figure 1), [22].

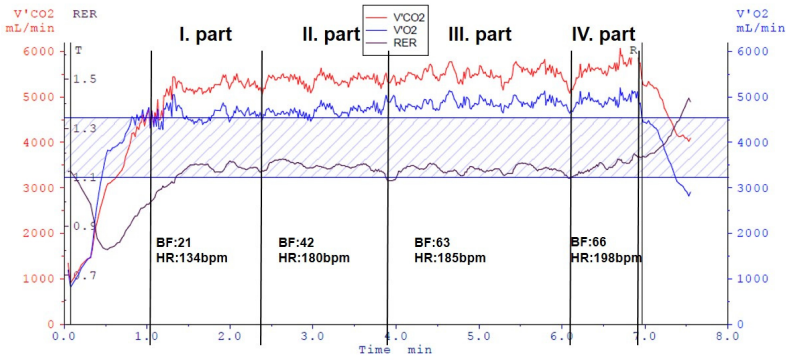


Figure 1. Breathing breakpoints ($VT_{1–3}$) based on differences in respiratory breakpoint in a 2000 m rowing ergometer competition. Legend: The figure shows the spiroergometric test of a male rower during a 2000 m rowing ergometer race. The data recorded during the test were divided into four sections based on each significant increase in respiratory rate (BF).

3. Results

We have found significant differences in body height (BH_m = 184.01 ± 6.22 BH_f = 172.38 ± 7.44); (t = 3.1505); $p < 0.0076$; body weight (BW_m = 74.51 ± 5.69-BW_f = 66.13 ± 6.77); (t = 2.4926); $p < 0.0269$ and body surface area (BSA_m = 1.96 ± 0.11-BSA_f = 1.78 ± 0.13); (t = 2.8595); $p < 0.0134$ between the two genders (Table 1).

Table 1. Anthropometric and cardiorespiratory characteristics.

	Mean $_m$	SD	Mean $_f$	SD	t-Value	df	*p*
age (year)	15.83	1.16	15.6	1.00	0.2960	13	0.7718
BH (cm)	184.01	6.22	172.38	7.44	3.1505	13	0.0076
BW (kg)	74.51	5.69	66.13	6.77	2.4926	13	0.0269
F%	13.36	5.46	25.11	6.30	−13.4973	13	0.000
M%	42.35	4.26	36.72	3.71	14.2215	13	0.000
BMI	21.98	0.90	22.19	0.83	−0.4632	13	0.6508
BSA (cm^2)	1.96	0.11	1.78	0.13	2.8595	13	0.0134
rHR (beat × min^{-1})	74.34	4.52	76.15	3.38	0.1860	13	0.4308

Legend: BH = body height (cm), BW = body weight (kg), BMI = body mass index (kg × m^{-2}), BSA = body surface area (m^2), rHR = resting heart rate (beat × min^{-1}), F% = relative body fat, M% = relative body muscle.

We have also found significant differences in relative body fat ($F\%_m = 13.36 \pm 5.46$–$F\%_f = 25.11 \pm 6.30$); (t = −13.4973); $p < 0.0000$ and relative muscle mass ($M\%_m = 42.35 \pm 4.26$–$M\%_f = 36.72 \pm 3.71$); (t = 14.2215); $p < 0.0000$ between the two genders.

We have found significant differences between the genders in the triple intensity zone (III. part) in all characteristics examined, except heart rate (HR_3), oxygen utilization (VE/VCO_2), respiratory exchange ratios (RER_3), and average respiratory rate (BF_3). The same was true for the averages measured at peak exercise (IV part), (Table 2).

Table 2. Results of rowing ergometric exercise tests (2000 m) in the laboratory by gender.

	Mean $_m$ (6)	SD	Mean $_f$ (9)	SD	t-Value	df	*p*
$Time_3$/sec.	208.83	87.66	333.78	97.51	−2.5262	13	0.0253
HR_3	187.17	5.00	182.78	9.44	1.0369	13	0.3187
O_2P_3	23.22	3.55	17.39	2.61	3.6852	13	0.0027
Q_3	43.41	6.27	31.65	3.90	4.5125	13	0.0006
VE_3	143.83	3.42	118.89	13.91	2.1715	13	0.0490
$VE/VO_{2\,3}$	33.22	4.96	36.55	3.40	−1.5534	13	0.1443
$VE/VCO_{2\,3}$	29.45	3.94	33.22	2.58	−2.2515	13	0.0423
$VO_{2\,3}$	4340.50	626.76	3164.56	389,56	4.5125	13	0.0006
$VCO_{2\,3}$	4880.67	680.55	3477.89	423.77	4.9540	13	0.0003
$rVO_{2\,3}$	58.01	4.45	47.92	4.55	4.2450	13	0.0010
RER_3	1.12	0.04	1.10	0.04	1.1033	13	0.2899
BF_3	61.17	5.51	60.44	2.33	0.3538	13	0.7292
VTin $[ST]_3$	2.03	0.29	1.67	0.18	2.9457	13	0.0114
$Time_{Peak}$/sec.	431.00	34.50	483.22	13.59	−4.1447	13	0.0012
HR_{Peak}	195.00	4.82	187.89	10.11	1.5927	13	0.1352
O_2P_{Peak}	22.60	3.92	17.01	2.70	3.2859	13	0.0059
Q_{Peak}	43.98	7.06	31.82	4.08	4.2573	13	0.0009
VE_{Peak}	153.33	36.27	122.67	12.99	2.3563	13	0.0348
VE/VO_2	34.82	4.92	38.80	3.40	−1.8596	13	0.0857
VE/VCO_2	30.22	4.03	34.69	3,04	−2.4549	13	0.0289
VO_2Peak	4397.83	705.68	3181.78	407.51	4.2573	13	0.0009
VCO_2Peak	5075.67	905.82	3560.11	465.65	4.2913	13	0.0009
rVO_2Peak	58.73	5.25	48.32	6.09	3.4136	13	0.0046
RER_{Peak}	1.15	0.04	1.12	0.04	1.7361	13	0.1062
BF_{Peak}	66.60	4.81	70.16	5.42	−1.2990	13	0.2165
VTin $[ST]_{Peak}$	2.01	0.38	1.54	0.18	3.2078	13	0.0069

Legend: Times/sec. = performance time (s); HR_3 = heart rate in Zone III (beats × min^{-1}); O_2P_3 = oxygen pulse in Zone III (mL × $beat^{-1}$); Q_3 = cardiac output in Zone III (L × min^{-1}); VE_3 = minute ventilation in Zone III (L × min^{-1}); $VE/VO_{2\,3}$ = ventilatory equivalent for O_2 in Zone III (—); $VE/VCO_{2\,3}$ = ventilatory equivalent for CO_2 in Zone III (—); $VO_{2\,3}$ = oxygen uptake in Zone III (L × min^{-1}); $VCO_{2\,3}$ = carbon dioxide output in Zone III (L × min^{-1}); $rVO_{2\,3}$ = relative oxygen uptake in Zone III (mL × kg^{-1} × min^{-1}); RER_3 = respiratory exchange ratio in Zone III (—); BF_3 = breathing frequency in Zone III (breaths×min^{-1}); VTin $[ST]_3$ = inspiratory tidal volume in Zone III (L); TimePeak/sec. = time to peak exercise (s); HR_{Peak} = heart rate at peak exercise (beats × min^{-1}); O_2P_{Peak} = oxygen pulse at peak exercise (mL×$beat^{-1}$); Q_{Peak} = cardiac output at peak exercise (L × min^{-1}); VE_{Peak} = minute ventilation at peak exercise (L × min^{-1}); VE/VO_2 = ventilatory equivalent for O_2 (—); VE/VCO_2 = ventilatory equivalent for CO_2 (—); VO_2Peak = oxygen uptake at peak exercise (L × min^{-1}); VCO_2Peak = carbon dioxide output at peak exercise (L × min^{-1}); rVO_{2Peak} = relative oxygen uptake at peak exercise (mL × kg^{-1} × min^{-1}); RER_{Peak} = respiratory exchange ratio at peak exercise (—); BF_{Peak} = breathing frequency at peak exercise (breaths × min^{-1}); VTin $[ST]_{Peak}$ = inspiratory tidal volume at peak exercise (L).

The values for males in terms of relative aerobic capacity (rVO_2max) were between 55 and 60 mL × kg^{-1} × min^{-1}, and respiratory exchange ratios (RER_{peak}) were between 1.1 and 1.2, which were close to each other.

The fourth and fifth places differ from the previous sample and are located in the opposite direction. The respiratory exchange ratios (RER_{peak}) values were close to the median (Figure 2A). In females, rVO_2max decreases with the number of places, and then increases again from sixth place to ninth place. The rVO_2max results of female competitors in ninth place were the highest (56–87 mL × kg^{-1} × min^{-1}). The two medians overlap. The respiratory exchange ratios (RER_{peak}) values are close to the median (Figure 2B).

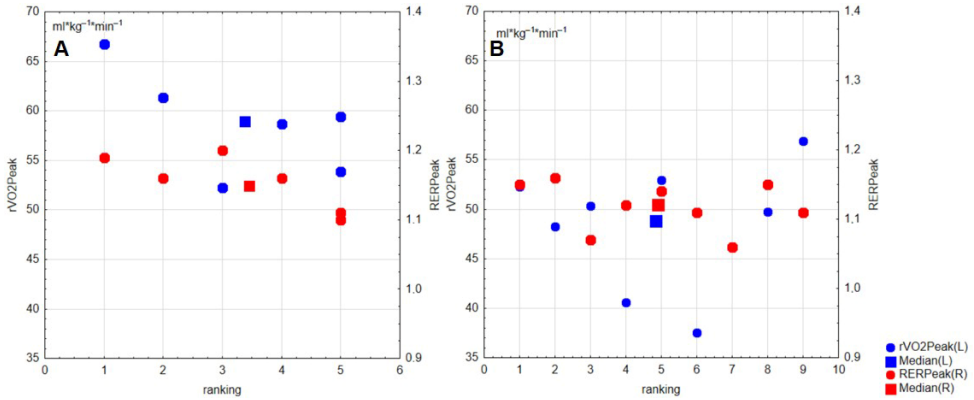


Figure 2. /A/B Rankings based on rowing ergometer test (2000 m), by gender. Legend: The figure marked (**A**) shows the results for males, while the figure marked (**B**) shows the results for females. The blue squares show the median values of relative aerobic capacity (rVO_2), (left y-axis), while the red squares show the median values of respiratory exchange ratios (RER_{peak}), (right y-axis). The blue and red full circles represent the individual averages of the two characteristics indicated above. The horizontal axis (x-axis) shows the order of the competitors participating in the test, (**A**) (1–5), (**B**) (1–9).

Significant negative correlations were observed between performance time ($Time_{Peak}$) and relative oxygen uptake (rVO_2Peak: r = −0.6781, $p < 0.010$), absolute oxygen uptake (VO_2Peak: r = −0.8286, $p < 0.001$), and oxygen pulse (O_2P_{Peak}: r = −0.7729, $p < 0.000$); (Table 3). These findings indicate that greater aerobic capacity and oxygen delivery efficiency were strongly associated with faster completion times in the 2000 m rowing test.

Table 3. Correlations between performance time and physiological variables at peak exercise.

	rVO_2Peak	**VO_2Peak**	**O_2P_{Peak}**	**$Time_{Peak}$**
$rVO2_{Peak}$		0.8848 ***	0.8404 ***	-0.6781 *
$VO2_{Peak}$	0.8848 ***		0.9753 ***	−0.8286 **
O_2P_{Peak}	0.8404 ***	0.9753 ***		−0.7729 *
$Time_{Peak}$	−0.6781 *	−0.8286 **	−0.7729 *	

Legend: * = $p < 0.050$; ** = $p < 0.010$; *** = $p < 0.000$; rVO_2Peak = relative oxygen uptake at peak exercise (mL × kg^{-1} × min^{-1}); VO_2Peak = oxygen uptake (L × min^{-1}); O_2P_{Peak} = oxygen pulse at peak exercise (mL × $beat^{-1}$); $Time_{Peak}$ = performance time.

4. Discussion

This represents one of the most demanding challenges for human physiology, primarily for the oxygen transport system, i.e., the transport of oxygen from the ambient air to the working muscles. During the standard spiroergometry test, the rowing ergometer was set up in a special room. The temperature (approx. 16–22 °C), humidity (30–60%) and ventilation of the room were controlled. The extreme effort associated with rowing can be explained by the seated posture and the simultaneous intensive use of the upper and lower limbs, which together increase cardiac output [22].

In the present study, we examined elite male and female rowers under laboratory conditions on a rowing ergometer. The task was to complete 2000 m in the shortest possible

time. Respiratory and circulatory parameters were continuously recorded during the test. We found significant differences between the sexes in terms of average height, body weight, and body surface area. We observed differences in virtually all variables examined in the intensity zones, except for four indicators (HR_3, VE/VCO_2, RER_3, BF_3).

The same was true for the averages measured at peak performance (Part IV). In terms of ranking, the highest rVO_2 values were observed in the top three finishers, regardless of gender. However, this correlation was not consistent. Performance is influenced by several other factors, such as the athletes' pacing strategy, which appears to be independent of final ranking and gender; the "fast start, then controlled middle section" profile has been consistently documented at world championships [23]. In rowing, a fast start has tactical and psychological significance, as the leading competitor can visually control the race. From a physiological point of view, it is not clear why this strategy would be optimal, as the balance between energy consumption and boat speed would undoubtedly justify a more even pace [24]. The strong negative correlations between performance time ($Time_{Peak}$) and both absolute and relative VO_2Peak as well as oxygen pulse (O_2P_{Peak}) observed in our study further confirm that aerobic capacity and oxygen transport efficiency are decisive determinants of 2000 m rowing performance in junior athletes.

According to the literature, VO_2max is indeed one of the strongest predictors of men's 2000 m ergometer time [11,12], and it also plays a significant role in women, especially when combined with supplementary tests (e.g., 30-s sprint or submaximal lactate responses) [10]. However, this relationship is not entirely linear, which, in line with our results, suggests that aerobic capacity is modulated by technical, tactical, and neuromuscular factors. At the same time, it should be emphasized that the ergometer is a standardized environment and is not equivalent to aquatic conditions with their variable resistance and synchronization requirements; thus, the correlation between ergometer and aquatic results may be weakened depending on the athlete cohort and methodology [2,8]. Another relevant consideration is the energy cost of rowing, which has been described in aquatic studies, where metabolic demand was not measured directly but modeled from the mechanical power required to overcome hydrodynamic resistance. Notably, Blervaque et al. were among the first to evaluate ergometer rowing while considering both measured oxidative and estimated glycolytic components [25].

The relationship between power and VO_2max also remains crucial [26]. This may explain why the female athlete with the highest rVO_2max in the present study still finished last. Since most of the mechanical work during rowing is performed by the lower limbs, this neuromuscular limitation may help explain why an increase in VO_2max does not necessarily result in a proportional increase in external work performed.

The practical implication is that training for junior athletes should not be limited to increasing VO_2max, but should also focus on the economy, respiratory thresholds (VT1–VT3), and psychological preparation. At the elite level, the 2000 m result is determined by the coordination of the efficiency of the energy supply system and the pace profile [4,27].

This study has several limitations, including the small sample size, its cross-sectional design, the exclusive use of ergometer testing instead of on-water conditions, and the restriction to elite Hungarian junior rowers, which limits generalizability; in addition, technical, strength-related, and psychological factors were not assessed.

5. Conclusions

The physiological differences that occur during extreme physical exertion are not surprising, but based on current data, no significant gender differences were found in the submaximal zone. This suggests that the real difference between the sexes manifests itself in the area of extreme physical exertion. In other words, body composition (greater muscle

mass) means higher metabolic requirements. In a vertical comparison, the distribution of individual breakpoints over time is largely proportional between the sexes; the difference is mainly apparent in the 2000 m performance. It is worth noting that the final ranking is not determined solely by current aerobic capacity, but it is influenced by a number of other factors, which confirms the multifactorial nature of performance: in addition to VO_2max, technical–tactical and psychological components are also decisive. Ergometer testing is suitable for individual monitoring and load control; however, final aquatic performance is also influenced by environmental and tactical factors [2,11,22]. Future research should incorporate larger and more heterogeneous samples, preferably in longitudinal designs, and include on-water testing as well as multidimensional performance determinants such as sex hormones, body composition, muscle fiber composition, and technical, strength-related, and psychological factors to provide a more comprehensive understanding of rowing performance.

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Abbreviations

The following abbreviations are used in this manuscript:

BF_3	breathing frequency in Zone III
BF_{Peak}	breathing frequency at peak exercise
BH	body height
BMI	body mass index
BSA	body surface area
BW	body weight
HR_3	heart rate in Zone III
HRPeak	heart rate at peak exercise
$O2P_3$	oxygen pulse in Zone III
$O2P_{Peak}$	oxygen pulse at peak exercise
Q_3	cardiac output in Zone III
Q_{Peak}	cardiac output at peak exercise
RER_3	respiratory exchange ratio in Zone III

RER_{Peak}	respiratory exchange ratio at peak exercise
rHR	resting heart rate
$rVO_{2\,3}$	relative oxygen uptake in Zone III
rVO_2Peak	relative oxygen uptake at peak exercise
VE_3	minute ventilation in Zone III
VE_{Peak}	minute ventilation at peak exercise
$VE/VCO_{2\,3}$	ventilatory equivalent for CO_2 in Zone III
VE/VCO_2	ventilatory equivalent for CO_2
$VE/VO_{2\,3}$	ventilatory equivalent for O_2 in Zone III
VE/VO_2	ventilatory equivalent for O_2
$VCO2_3$	carbon dioxide output in Zone III
VCO_2Peak	carbon dioxide output at peak exercise
$VO_{2\,3}$	oxygen uptake in Zone III
VO_2Peak	oxygen uptake at peak exercise
VTin $[ST]_3$	inspiratory tidal volume in Zone III
VTin $[ST]_{Peak}$	inspiratory tidal volume at peak exercise

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