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Comparison of Anthropometric and Physiological Profiles of Hungarian Female Rowers across Age Categories, Rankings, and Stages of Sports Career

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Abstract: There is very little research on the anthropometric and physiological profiles of lower-ranked young female athletes, even though, in most rowing clubs, such rowers constitute the vast majority. Therefore, this study investigated the anthropometric and physiological profiles of young Hungarian female rowers of different age categories and sports rankings (international vs. club). Anthropometric and physiological profiles were created for 36 junior (15–16 years), 26 older-junior (17–18 years), and 8 senior (19–21 years) female rowers who were club and international ranked members of seven of the largest Hungarian rowing clubs. Rowers >17-years-old with international rankings significantly outperformed their age-group peers with club rankings in terms of power, absolute $VO_{2\,max}$, and time to cover 2000 m, among other differences, but such differences were not observed with junior rowers. In all age groups, the length of the athletes' sports career was not significantly associated with differences in anthropometric and physiological characteristics. This study suggests that ranking is not associated with differences in the anthropometric and physiological characteristics of juniors. Thus, with non-elite juniors, it can be more difficult to predict competition outcomes based on differences in anthropometric and physiological profiles.

Keywords: rowing; age groups; anthropometric characteristics; physiological parameters; female

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Citation: Podstawski, R.; Borysławski, K.; Ihasz, F.; Pomianowski, A.; Wąsik, J.; Gronek, P. Comparison of Anthropometric and Physiological Profiles of Hungarian Female Rowers across Age Categories, Rankings, and Stages of Sports Career. *Appl. Sci.* **2022**, *12*, 2649. https://doi.org/10.3390/app12052649

Academic Editor: Jesús García Pallarés

Received: 29 January 2022
Accepted: 1 March 2022
Published: 4 March 2022

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1. Introduction

In rowing, sufficient force needs to be generated with each stroke to reaccelerate the boat [1]. Thus, motor performance capabilities in rowing do not depend solely on technical execution, but also on the biomechanical and physiological characteristics of the athletes [2–9]. There are two different types of rowing techniques: fixed seat rowing, in which the rower is supported on a fixed bench, and sliding seat rowing, in which the rower is seated in a sliding seat that allows body movement from stern to bow, and vice versa [9]. In sliding seat rowing, including the Olympic modality, which is the subject of the present study, the force generated by the lower body is of greater importance to rowing performance [7,10].

Research suggests that anthropometric variables (i.e., body mass, body height, length of legs, and body span) and the muscular strength endurance of the trunk and upper and lower limbs are associated with rowing performance [8,11]. The lower limbs produce approximately 46.6% of total rowing power, the trunk produces 30.9%, and the arms and shoulders produce 22.7% [12]. Therefore, proportionally long arms and legs (i.e., long levers) and large size bodies provide a biomechanical advantage for sweep rowers [13,14].

Although there is an abundance of literature concerning elite rowers at the highest levels, such as Olympic and World Championship finalists [13,15–18], reports on developing female rowers are relatively rare and fewer than those devoted to men. Moreover, it narrows down considerably if we consider studies comparing rowers of different age categories [3]. Comparative research with a group of traditional male and female rowers revealed that body height was the best predictor of performance for male rowers, whilst muscle mass was the best predictor for female rowers [19]. Correspondingly, research examining Olympic modality junior rowers suggests that they tend to be similar to adult heavyweight rowers in stature, but the adults have greater length, range, and girth dimensions, and they tend to be heavier than the juniors [2,3,15]. Body composition is one of the indicators used for selecting athletes for rowing teams [5]. It stems directly from the fact that in sports demanding high force production, muscle mass may be closely associated with performance outcomes [20,21], and consequently, in Olympic rowing in particular, greater fat-free body mass may favor increased performance in competition [9,22]. A 2000 m Olympic rowing competition requires a mixture of aerobic and anaerobic power [23]. These events require maximum exertion for a duration of 5 to 7 min [24]. During this time, the relative anaerobic contribution ranges from 21 to 30% [25], which means that, in addition to a large aerobic capacity, a highly developed anaerobic capacity is also essential for successful international performance [26,27]. The aerobic metabolism covers 70–80% of energetic demands in a rowing race, and there are two parameters for an assessment of aerobic metabolism: maximum oxygen uptake (VO_{2max}) and a lactate anaerobic threshold defines by mean of lactic acid concentration in the blood in the amount of 4mmol/L [1]. Top class rowers are reported to achieve the highest VO_{2max} ever measured, which regularly exceeds values of 5 L/min, and values above 7 L/min have also been reported [28].

However, it is still unclear whether elite rowing athletes significantly differ in terms of anthropometric and physiological characteristics from their non-elite peers, which can create difficulties in screening for selection purposes. Moreover, ability to grasp differences in such differences become even more blurred when the groups being compared are relatively young and comparable in age, and the rowing performance of the best rowers has not yet reached the highest level that would classify them as elite rowing athletes [29].

The purpose of this study was to help fill the gap in knowledge regarding developing female rowing athletes by determining the anthropometric and physiological profiles of Hungarian female rowers of different age categories (15–16, 17–18, and 19–21 years), sports rankings (international vs. club), and lengths of time as licensed rowers (seniority). It has to be said that the best Hungarian female rowers pretend to be outstanding rowers and have not yet achieved such spectacular successes as the finals of the World Championships or the Olympic Games. For these reasons, finding potential differences using the above-mentioned independent variables may be more difficult. On the other hand, such rowers constitute the vast majority of the rowing community, with honorable successes accruing to a few. Coaches with young athletes aspiring to be among the best may find it difficult to select the most talented and promising for the future. It was hypothesized that the anthropometric and physiological characteristics of the female rowers, their performance over a 2000 m distance, and their performance on motor tests would differ depending on their age, ranking, and seniority.

2. Materials and Methods

2.1. Participants

This study was conducted in 2021 for three days at Gyor rowing club, finishing 10 days before the first rowing regatta of the competition period. The sample consisted of 70 junior female rowers from the seven largest Hungarian rowing clubs. The rowers regularly took part in national and international competitions. They were classified by age as juniors

(N = 36, range: 15–16 years), older juniors (N = 26, range 17–18 years), and seniors (N = 8; range: 18–21 years). The following criteria were applied for inclusion in the sample: in all age groups, the female rowers needed to have a current license and to take part in inter-club (national) and/or international competitions. All participants had up-to-date medical examinations. They regularly participated in training that followed the Hungarian Rowing Federation Training Plan (15–16-year-olds: 12–13 h/week; 17–18-year-olds: 14–15 h/week; 19–22-year-olds: 16–17 h/week). The ratio of aerobic to anaerobic exercise was 80:20% for the 15–16-year-olds, 75:25% for the 17–18-year-olds, and 70:30% for the 19–22-year-olds. Internationally ranked participants participated in up to three training sessions organized by the Hungarian Rowing Federation each year. The rowers training during the year before the measurements was affected by the Covid-19 pandemic. All research participants were volunteers; they were informed of the research purpose, the data collection procedures and techniques, and possible risks. The participants signed a consent form, which also guaranteed their anonymity, data confidentiality and the right to withdraw from the study at any time.

2.2. Ethical Statement

This study was conducted in accordance with both the Declaration of Helsinki and the guidelines and policies of the Health Science Council, Scientific and Research Ethics Committee (IV/3067-3/2021/EKU) in Hungary.

2.3. Procedures, Data Collection and Equipment

The participants were advised to eat a light meal (800–1200 kcals) that consisted of 60–70% carbohydrates no later than 4 h prior to the beginning of the day's tests.

Anthropometric and physiological tests were performed with each female rower at the beginning of the 2020 racing season. On day one, anthropometric features were measured, on day two, the athletes performed motor tests, and on day three, they covered 2000 m on a Concept II rowing ergometer. The rowing coaches of the sports clubs were instructed not to give the participants any strenuous training on the day before testing began. The coaches assisted the researchers with the measurements. To measure body height to the nearest 1 mm, a calibrated Soehlne Electronic Height Rod 5003 (Soehlne Professional, Germany) was used, following standardized guidelines. For body mass (to the nearest 0.1 kg), BMI and body composition, i.e., body fat percentage (BFP) and skeletal muscle mass (SMM), an InBody 720 body composition analyzer was employed. As for sitting height (cm), arm span (cm), lower limb length (cm), BSA (m^2) and other anthropometric characteristics, the methods of Weiner and Lourie [30] were used. To measure skin folds (biceps, triceps, scapula, suprailiac, abdomen, thigh, lower leg), a Harpenden caliper was used.

2.4. Estimation of Relative Body Fat Content

The expression body composition indicates the ratio of various body substances (for instance: water, protein, fat, muscles bone, different minerals, etc.) within the whole body. The more often used techniques estimate the ratio of depot fat and lean body mass or fat free mass (body mass—depot fat and essential fat mass). Variability among the results of different body fat estimates gives the reason to use such skinfold techniques by which representative references are available, and the technique was validated by densitometric procedure. The calipermetric estimation of relative body fat content, developed by Pařízková [31], meets both conditions mentioned. Therefore, for estimation of relative body fat content, calipers were used to measure five skinfold thicknesses: over the biceps and triceps, subscapular, suprailiac, and medial calf. The sum of these measurements was multiplied by two, and the result was matched to the estimated relative body fat content in a table.

2.5. Countermovement Jumping

The power output of the lower extremities and the height attained by the center of body mass during vertical jumps were measured with a PJS-4P60S force plate ("JBA" Zb. Staniak, Poland) at a sampling frequency of 400 Hz with maximum linearity error of the force measuring path of <0.5% [29]. The amplifier was connected to a PC via an A/D converter. For measurement, the MVJ v. 3.4. software package ("JBA" Zb. Staniak, Poland) was used. In the physical model that was used for calculations, the subject's body mass was treated as a point affected by the vertical components of external forces: the force of gravity acting on the body and the vertical component of the platform's reactive force. Each subject performed three counter-movement jumps (CMJ) with maximal force. A CMJ is a vertical jump from a standing erect position, preceded by a counter- movement of the upper limbs and lowering of the body mass center before take-off. Each subject was asked to perform a countermovement jump from the force plate to determine maximal force (N) and the rate of displacement (m/s). From these measurements, jump height (via ground reaction force integration) (cm) and peak power (W) were determined. Using the body mass of the subject, the relative peak power (W/kg) was calculated.

2.6. 2000 m Maximal Rowing Ergometer Test

The participants were asked to perform an all-out 2000 m test on a certified rowing ergometer (Concept 2 D-model). The screen of the ergometer was set to display the number of meters remaining, the average time for 500 m and the accumulated time.

The power output in watts (W) was measured over 2000 m. The calculation of watts was performed as follows. First, the distance was defined: distance = (time/number of strokes) $\times$ 500. In the next step, the concept of a "split" was clarified: split = 500 $\times$ (time/distance). The watts were calculated as 2.8/(split/500). There were slight differences in intensity due to individual changes in stroke value and ability to keep the 500 m split time constant. Prior to all tests, all participants warmed up for 6 min over a 500 m distance, then rested for 6 min while performing stretching exercises. The estimated relative aerobic capacity ($ErVO_2$) was calculated using the formula of McArdle et al. [32] for women: $ErVO_2$ = (Y $\times$ 1000)/BM, where BM is body mass, and Y = (BM < 61.36 kg; 14.6.1 $-$ (1.5 $\times$ time)]; BM = > 61.3 kg; 14.6 $-$ (1.5 $\times$ time)). The power generated over 2000 m was divided by the subject's body weight to obtain the relative performance (rW 2k).

2.7. Statistical Analysis

Measurements were statistically processed with Statistica PL, v. 13.5. Based on the median length of involvement in rowing competitions (juniors, 3 years; older juniors, 5 years; seniors, 7 years), the participants in each age category were further divided into two subcategories: greater and lesser seniority. The athletes were ranked as international (participants in international competitions) or club (participants in national inter-club competitions) level. The Shapiro–Wilk did not indicate significant deviations from normality. Therefore, for comparisons of two arithmetic means, Student's *t*-test was used. To compare three arithmetic means, one-way analysis of variance (ANOVA) was used. If ANOVA indicated a significant difference, Tukey's Honestly Significant Difference (HSD) test was used for post-hoc analysis. Statistical significance was set at $p \leq 0.05$.

3. Results

3.1. Anthropometric and Physiological Characteristics and Motor Performance of Female Rowers in Different Age Groups

Table 1 presents the anthropometric, motor performance, and physiological characteristics, as well as the body composition of female rowers in the following age categories: junior (15–16 years), older junior (17–18 years), and senior (>18 years).

Table 1. Comparison of arithmetic means of women's anthropometric, physiological and motor parameters depending on the age categories.

Parameter		Age Category (Years)									Difference		HSD (Post-Hoc)			Cohen's *d*		
		(1) 15–16 (N = 36)			(2) 17–18 (N = 26)			(3) 19–22 (N = 8)										
		Mean	SD	Min-Max	Mean	SD	Min-Max	Mean	SD	Min-Max	*F*	*p*	1–2	2–3	1–3	1–2	2–3	1–3
Body height (cm)		166.63	7.64	156.70–187.10	170.21	6.74	160.00–187.40	171.58	4.14	166.20–179–80	2.83	ns	ns	ns	ns	0.50	0.23	0.80
Body mass (kg)		60.70	7.08	49.20–76.40	65.95	7.85	53.20–84.10	71.19	6.49	63.20–81.50	8.43	<0.001	0.019	ns	0.001	0.69	0.71	1.53
BFP (%)		23.81	5.73	13.90–32.10	25.37	6.68	8.30–35.30	30.15	5.52	19.90–36.20	3.59	0.033	ns	ns	0.026	0.25	0.78	1.12
SMM (%)		34.15	2.88	29.00–41.30	33.57	4.48	28.00–47.40	31.60	4.02	28.00–40.90	1.58	ns	ns	ns	ns	0.15	0.46	0.72
BMI (kg/m^2)		21.86	2.01	18.81–26.42	22.74	2.15	18.48–27.19	24.17	1.84	21.12–26.47	4.60	0.013	ns	ns	0.014	0.42	0.71	1.19
Sitting height (cm)		88.38	3.89	83.10–100.00	90.60	3.61	85.40–99.90	91.01	2.01	88.00–93.20	3.59	0.033	0.050	ns	ns	0.59	0.14	0.84
Arm span (cm)		168.22	8.08	155.40–188.00	172.30	7.72	159.50–192.00	176.19	5.56	168.40–185.00	4.43	0.016	ns	ns	0.028	0.51	0.57	1.14
Lower limb length (cm)		95.86	6.10	85.40–112.40	98.35	5.89	87.90–112.50	96.01	2.85	93.90–102.40	1.49	ns	ns	ns	ns	0.41	0.50	0.03
BSA (m^2)		1.41	0.22	1.07–1.94	1.56	0.23	1.21–2.19	1.70	0.18	1.52–2.04	7.44	0.001	0.022	ns	0.004	0.66	0.67	1.44
Skin folds (mm)	Biceps	10.69	4.07	3.00–22.00	9.73	3.34	5.00–17.00	9.88	2.85	6.00–15.00	0.56	ns	ns	ns	ns	0.25	0.04	0.23
	Triceps	18.89	4.73	10.00–29.00	18.85	4.97	10.00–31.00	22.75	3.45	20.00–29.00	2.41	ns	ns	ns	ns	0.00	0.91	0.93
	Scapula	14.69	4.31	8.00–24.00	15.27	4.41	9.00–23.00	17.75	3.92	12.00–24.00	1.65	ns	ns	ns	ns	0.13	0.59	0.74
	Suprailiac	14.33	4.50	6.00–24.00	13.15	4.40	5.00–25.00	15.00	1.31	13.00–17.00	0.85	ns	ns	ns	ns	0.26	0.56	0.20
	Abdomen	17.31	6.65	8.00–36.00	15.15	3.93	7.00–22.00	18.00	4.75	15.00–29.00	1.41	ns	ns	ns	ns	0.39	0.65	0.11
	Thigh	24.25	7.19	10.00–38.00	26.42	5.69	14.00–38.00	31.38	5.26	26.00–41.00	4.11	0.021	ns	ns	0.018	0.33	0.90	1.13
	Lower leg	16.86	5.07	6.00–25.00	16.77	4.28	10.00–25.00	20.13	3.23	15.00–24.00	1.82	ns	ns	ns	ns	0.01	0.88	0.76
Body fat (%) *		30.41	4.10	22.90–36.50	31.44	2.52	26.50–36.90	33.00	2.73	27.90–35.60	1.68	ns	ns	ns	ns	0.30	0.59	0.74
Peak power (W)		182.09	30.12	129.00–246.00	212.92	27.85	155.00–261.00	254.75	38.24	180.00–294.00	20.96	<0.001	0.001	0.004	<0.001	1.06	1.25	2.11
RPP (W/kg)		3.01	0.42	2.25–3.73	3.23	0.36	2.35–4.01	3.57	0.37	2.79–4.12	7.40	0.001	ns	ns	0.002	0.56	0.93	1.41
Time 2000 m (min)		8.34	0.47	7.50–9.30	7.90	0.36	7.35–8.75	7.45	0.41	7.07–8.32	17.28	<0.001	<0.001	0.032	<0.001	1.05	1.16	2.01
ErVO$_{2\ max}$ (mL/kg/min)		52.52	9.98	30.59–67.70	58.37	6.82	41.08–73.26	63.53	6.25	49.82–71.91	6.81	0.002	0.034	ns	0.005	0.68	0.78	1.32
ErVO$_2$max (L/min)		3.19	0.71	1.75–4.45	3.85	0.53	2.58–4.67	4.53	0.62	3.22–5.10	17.28	<0.001	0.002	ns	<0.001	1.05	1.01	1.86
Jump height (cm)		28.77	4.61	20.70–37.60	27.90	3.10	21.60–33.70	28.39	2.34	25.00–32.90	0.37	ns	ns	ns	ns	0.22	0.17	0.10
Speed max (m/s)		2.29	0.21	1.89–2.65	2.25	0.13	1.97–2.49	2.29	0.11	2.09–2.46	0.35	ns	ns	ns	ns	0.22	0.33	0.00
Force max (N)		1282.25	194.70	950–1916	1370.39	145.40	1124–1690	1489.38	146.00	1319–1708	5.39	0.007	ns	ns	0.009	0.51	0.81	1.20
RPM (W/kg)		40.42	5.94	30.10–52.70	38.95	3.86	30.60–45.70	38.91	3.36	32.7–42.4	0.76	ns	ns	ns	ns	0.29	0.01	0.31

* Pařízková's formula, ns—not significant differences, SMM—skeletal muscle mass, RPP—relative peak power, RPM—relative maximal power, Cohen's *d*—effect size, SD—standard deviation, HSD—honest significant difference.

Body height did not differ significantly between the groups. However, seniors (+10.50 kg, p = 0.001) and older juniors (+5.25 kg, p = 0.019) had significantly higher body mass than female juniors. Additionally, senior females had significantly higher values of body fat percentage (+6.34%, p = 0.026), BMI (+2.31 kg/m^2, p = 0.014), arm span (+7.97 cm, p = 0.028), and thigh skin fold (+7.13 mm, p = 0.018) than junior female rowers. As for anthropometric characteristics, the groups did not differ significantly in terms of SMM, lower limb length, body fat percentage (Pařízková formula), and measurements of skin folds on the biceps, triceps, scapula, suprailiac, abdomen, and lower leg.

In motor performance tests, the senior female rowers covered the distance of 2000 m in the best time (7.45 min), which was significantly shorter than that of the older juniors (–0.45 min., $p < 0.032$) and juniors (–0.80 min., $p < 0.001$). Additionally, the older juniors had a significantly shorter time than the juniors (–0.40 min, $p < 0.001$). Female seniors and older juniors achieved significantly higher values of VO_{2max} in both relative (+11.01 mL/kg/min, p = 0.005 and +5.86 mL/kg/min, p = 0.034, respectively) and absolute (+1.34 L/min, $p < 0.001$ and +0.66, p = 0.002, respectively). The senior rowers developed the greatest power (254.80 W), which was significantly higher than that of the juniors (+72.66 W, $p < 0.001$) and older juniors (+41.83W, p = 0.004), and the older juniors generated significantly more power than the juniors (+30.83 W, p = 0.001). The senior females achieved significantly higher relative power and force max than the juniors (+0.56 W/kg, p = 0.002; and +207.13 N, p = 0.009). However, jump height, speed max, and RPM did not differ significantly between the groups.

3.2. Comparison of Anthropometric and Physiological Characteristics and Motor Performance between Club-Level and International-Level Female Rowers

Table 2 presents the relevant comparisons between junior athletes at club level and those at international level. The junior club-level rowers had significantly larger skinfold measurements than their international-level peers: scapula (+3.36 mm, p = 0.029), suprailiac (+3.49 mm, p = 0.030), abdomen (+4.89 mm, p = 0.040), thigh (+6.12 mm, p = 0.016), and lower limb (+4.17 mm, p = 0.021). However, the junior international-level rowers developed significantly higher RPP (+0.30 W/kg, p = 0.046).

Table 2. Comparison of arithmetic means of younger junior women's anthropometric, physiological and motoric parameters depending on the ranking categories.

Parameter	Ranking Category				Difference		Cohen's *d*
	International (N = 11)		Club (N = 25)				
	Mean	SD	Mean	SD	*t*	*p*	
Scapula skinfold (mm)	12.36	2.77	15.72	4.50	−2.28	0.029	0.89
Suprailiac skinfold (mm)	11.91	3.78	15.40	4.43	−2.27	0.030	0.85
Abdomen skinfold (mm)	13.91	4.78	18.80	6.87	−2.14	0.040	0.87
Thigh skinfold (mm)	20.00	6.47	26.12	6.79	−2.53	0.016	0.79
Lower leg skinfold (mm)	14.00	5.42	18.17	4.41	−2.41	0.021	0.83
RPP (W/kg)	3.21	0.45	2.91	0.37	2.08	0.046	0.84

Table 3 shows comparisons between older junior female rowers at club level and those at international level. The internationally ranked older juniors were significantly taller (+5.36 cm, p = 0.040) and heavier (+6.80 kg, p = 0.024), and they had a significantly longer arm spans (+8.60 cm, p = 0.002) and lower limb length (+5.75 cm, p = 0.010), BSA (0.21 m^2, p = 0.017), as well as significantly lower abdomen skinfold measurements (−3.53, p = 0.018) than their peers with club level. On the rowing ergometer, the older international-level older juniors developed significantly higher power (+23.18 W, p = 0.039) and absolute values of VO_{2max} (+0.45 L/min) and covered 2000 m in significantly less time (−0.30 min, p = 0.035).

Table 3. Comparison of arithmetic means of older junior female rowers anthropometric, physiological, and motoric parameters depending on the ranking categories.

Parameter	Ranking Category				Difference		Cohen's *d*
	International (N = 13)		Club (N = 13)				
	Mean	SD	Mean	SD	*t*	*p*	
Body height (cm)	172.89	6.94	167.53	5.55	2.17	0.040	0.85
Body mass (kg)	69.34	7.26	62.56	7.12	2.40	0.024	0.94
Arm span (cm)	176.59	6.74	168.00	6.23	3.38	0.002	0.86
Lower limb length (cm)	101.22	5.51	95.47	4.88	2.82	0.010	0.93
BSA (m^2)	1.67	0.23	1.46	0.19	2.56	0.017	0.94
Abdomen skinfold (mm)	13.39	2.96	16.92	4.07	−2.53	0.018	1.00
Watt 2000m (W)	223.54	23.02	200.36	28.78	2.19	0.039	0.89
Time 2000m (min)	7.76	0.28	8.06	0.38	−2.25	0.035	0.89
$ErVO_{2max}$ (L/min)	4.06	0.41	3.61	0.57	2.25	0.034	0.91

As for the senior females, the international-level rowers had a significantly larger/smaller skin suprailiac skin fold (2.00 mm, $p = 0.049$) than the club-level rowers. Additionally, although the evidence was not strong enough to meet the pre-established criterion for statistical significance, the internationally ranked senior rowers had better values for most of the analyzed anthropometric traits than their club level peers (body height, body mass, BFP, SMM percent, BMI, sitting height, arm span, lower limb length, BSA, other skin folds).

3.3. Relations between Anthropometric and Physiological Characteristics of the Female Rowing Athletes in Different Stages of the Sports Careers

In all age categories, the length of the athletes' sports career was generally not associated with significant differences in anthropometric and physiological characteristics. Juniors with shorter sports careers were significantly taller (+6.30 cm, $p = 0.011$) and had significantly longer arm span (+6.40 cm, $p = 0.016$) and lower limb length (+4.10 cm, $p = 0.043$) than their age-group peers with longer careers. Among older juniors, those with shorter sports careers had significantly larger suprailiac skinfolds (+3.50 mm, $p = 0.038$) than those with longer careers. As for the seniors, those with shorter sports careers had significantly longer arm spans (+7.90 cm, $p = 0.029$) and larger suprailiac skinfolds (+2.00 mm, $p = 0.13$).

4. Discussion

The purpose of this study was to examine the anthropometric and physiological profiles and motor performance of Hungarian female rowing athletes in different age groups, competing at different levels, and with different lengths of time as licensed rowers.

The literature suggests that the anthropometry of world-class rowers appears to have altered during the past 30 years toward a more compact, robust physique, which is especially noticeable amongst female competitors [5,33]. Similarly, this study found significant differences between the anthropometric and physiological characteristics of Hungarian female rowers in different age groups, as older (>17 years) Hungarian female rowers were significantly heavier, possessed larger BSA and had significantly higher BFP, BMI, arm span, and thigh skinfold values than their younger peers (15–16 years). The results of this study are supported by previous research conducted by Schranz et al. [22], which found that the body mass of junior female rowers (60.7 kg) was slightly above the upper limit for lightweight female rowers (59.0 kg).

Changes in the fat mass and lean body mass of women gradually take place due to lipase activity induced by estrogen, resulting in fat accumulation mainly around women's hips and thighs [34]. This study found that the body mass of junior female rowers was significantly lower than that of older juniors and seniors, and the BMI of the junior female rowers (closer to the lower limit of the standard) was significantly lower than the BMI of the seniors (closer to the upper limit of the standard). This might suggest that the process of changes in the distribution of fat mass and lean body mass had not yet been fully completed in the Hungarian junior female rowers. This supposition may be supported by the lack of significant differences in BFP between the study participants in different age categories. However, when considering these results, it must be noted that the BMI does not give reliable information about the body composition of sport athletes and does not allow an important distinction to be made between the distribution of fat and muscle tissue in the lower and upper half of the body [35,36]. In terms of a body height, there were no significant differences between the age groups. The lack of significant differences might be due to the fact that the bones of women reach their final length after 2–4 years of puberty [37].

The results of the physiological tests showed that the relative and absolute values of Er VO_{2max} were significantly higher between seniors and older juniors vs. young juniors, but they did not differ significantly between the older juniors and seniors. The lack of significant changes between the older juniors and the senior group may be caused by the relatively small age difference, and the oldest oarsmen were 21 years old. A different phenomenon was observed in a study of seven age groups of Polish female rowers (age range 15–22 years), which recorded the highest significant increases in absolute VO_{2max} values in 20–22-year-old females, but did not record significant increases in relative values [38]. As indicated by a number of reports from studies of female and male rowers [39–42], maximal oxygen uptake is of high diagnostic value when it is expresses in absolute values (L/min). On the other hand, a longitudinal study of successful Croatian quadruple scull rowers found the largest improvement in maximal oxygen uptake (in absolute values) at ages of about 19.2–20.2 years [43]. Messonier et al. [44] reported that, in top rowers, VO_{2max} increased markedly to age 23 and then slightly increased until 28 years of age.

In terms of the female rowers' ranking, the results presented here indicate that it is not associated with noticeable differences in anthropometric and physiological characteristics, with the exception of older junior female rowers. In this age category, the elite rowers had significantly better anthropometric traits, and developed significantly higher power by covering 2000 m in significantly less time than club-level rowers, while achieving significantly higher absolute values of VO_{2max} [L/min]. These results are in line with previous research that suggests that elite rowers tend to develop better technique, demonstrating a more efficient recovery phase, a faster stroke rate and the muscle strength, endurance and power required for a stronger, more consistent, and effective propulsive stroke [10,45–47]. Furthermore, the present study indicates that length of rowing career has little or no effect on the anthropometric and physiological traits of Hungarian female rowers in all age groups. This lack of effect may be due to the fact that Hungarian female rowers with international ranking are not among the best in the world.

The lack of significant differences in individual age categories when variables such as ranking (except older juniors) and competition seniority were taken into account stands in contrast to numerous studies conducted by other authors. However, those authors compared the finalists of major rowing events with intermediate rowers. In contrast, even though the examined group of Hungarian rowers had individuals with club and with international rankings, the latter had not achieved notable success in the international arena. As a result, the relatively young sample that was analyzed was less diverse in terms of anthropometric and physiological profiles, and potential differences were much more difficult to detect. From a practical point of view, trainers may find it difficult to select the most promising rowers because the performances that they ultimately achieve can be influenced by external factors (organizational, financial, or motivational) that are not directly linked with endogenous factors (anthropometric and physiological characteristics).

Strengths and Limitations

This paper makes a novel contribution to the literature by providing information about the anthropometric and physiological characteristics of Hungarian junior female rowers through an analysis of how these characteristics vary depending on age, ranking, and stage of sports career. These findings may serve as comparative material for further studies in this field, especially as there are a small number of publications dealing with the issue of differences in anthropometric and physiological characteristics of female rowers representing various age groups. It should be noted that weight categories were not used to classify the rowers in this study due to their relatively young age. The limitations of this study were associated with sampling, time, and logistical constraints. Although the sample was relatively homogeneous, it is likely to be highly representative of Hungarian rowers as a whole. Regarding time and logistical limitations, all measurements were performed within a timeframe of 3 days to minimize disturbances to the athletes' training and changes in their condition. Therefore, due to limited time, this study did not examine heart rate (HR) values (min, avg, and max), lactate anaerobic threshold values, and all indicators of acid-base balance, such as the concentration of lactic acid in the blood, alkaline deficiency or excess, blood pH and current molecular pressure of CO_2. Nonetheless, the study obtained valid results with regards to differences between age groups and VO_{2max}, which is considered the "gold standard" for cardiorespiratory fitness. To complement the results of this study, future studies could examine indicators of acid-base balance, i.e., blood pH, partial pressure of CO_2 in arterial blood (pCO_2), HCO_3^- ion concentration, and alkaline deficiency or excess (BE). Moreover, the authors suggest conducting a repeated study on the same group of athletes during different training periods.

5. Conclusions

This study tested the hypothesis that the anthropometric and physiological characteristics of junior female rowing athletes, their performance over a 2000 m distance, and their performance on motor tests would differ depending on their age, ranking, and length of sports career. The results suggest that Hungarian female rowers in older age categories have higher values of anthropometric and physiological characteristics than younger athletes. Within the older junior category, these traits are significantly better among female athletes with international rankings. The length of sports career was not associated with significant differences in anthropometric and physiological characteristics within different age groups. Overall, this study indicates that, with non-elite rowers, it can be more difficult to predict competition outcomes based on differences in anthropometric and physiological profiles. Therefore, athletes with superior aptitude for rowing are more difficult to select from among lower-ranking rowers. This initial study could be used as a basis for future research that would assess more accurately whether anthropometric and physiological characteristics and the results of motor tests should play an important role in selection for female rowing competitions. Finally, these findings could be complemented with a longitudinal study that examines how these characteristics change in female athletes as the rowing season progresses or over several years of their sports careers.

Author Contributions: Conceptualization, R.P. and F.I.; methodology, F.I. and R.P.; software, F.I. and R.P.; validation, F.I., R.P. and K.B.; formal analysis, K.B. and F.I.; investigation, F.I. and R.P.; resources, R.P.; data curation, R.P.; writing—original draft preparation, R.P., A.P., J.W. and P.G.; writing—review and editing, R.P., A.P., J.W. and P.G.; visualization, K.B.; supervision, R.P.; project administration, F.I.; funding acquisition, R.P. and A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by University of Warmia and Mazury in Olsztyn, Poland, and comes from private sources.

Institutional Review Board Statement: The studies involving human participants were reviewed and approved by Health Science Council, Scientific and Research Ethics Committee (IV/3067-3/2021/EKU).

Informed Consent Statement: Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Data Availability Statement: The Excel data used to support the findings of this study are restricted by the Ethics Committee of the University of Warmia and Mazury in Olsztyn (UWM), Poland in order to protect participants' privacy. Data are available from RP, e-mail: podstawskirobert@gmail.com for researchers who meet the criteria for access to confidential data.

Acknowledgments: The authors would like to thank all rowers who volunteered for the study.

Conflicts of Interest: The authors declare no conflict of interest.

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