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Sex-Related and Performance Differences in Contractile Properties, ROM, Strength, and Dynamometry Performance of World-Class Flatwater Canoeists

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Abstract: The inclusion of women canoe in the Olympic Games reflects the growth and development that women have ahead of them in this modality. Therefore, the aim of this study was to explore sex and performance level differences in muscle contractile properties through Tensiomyography (TMG), range of motion (ROM), strength, and canoe-specific functional electromechanical dynamometry (FEMD) performance and establish performance differences between international medalists and non-medalists. Twelve male and nine female canoeists from the Spanish and Portuguese national canoe teams were assessed through TMG, ROM, strength, and canoe-specific isometric and incremental FEMD tests. Few sex and performance level differences were found in TMG and ROM; however, significant sex differences were found in the strength and FEMD tests. Male canoeists had a greater Fmax in Leg Press, Pm and Pmax in canoe position cable row, 1RM bench press and bench pull, Fm and Fpeak canoe-specific isometric FEMD test and number of strokes, and Fpeak and Pmax on the incremental FEMD test than females. International medalists showed a lower time until reaching Vmax and Pmax in Leg Press on both sides and a greater number of strokes and Fpeak in the maximal incremental FEMD test than non-medalists. This study reinforces the utility of the use of TMG and FEMD for assessing and monitoring world-class athletes.

Keywords: canoe; gender; tensiomyography; functional strength

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1. Introduction

Flatwater canoeing has been an Olympic sport since 1936 where two modalities are differentiated, kayak and canoe. These modalities mainly differ in the boat, the type of paddles, and their technical motor pattern. Kayakers are seated in a kayak and use a double-blade paddle for propulsion, while canoeists paddle from a kneeled position using a single-blade paddle.

Although both female and male kayakers and canoeists currently compete internationally over the same distances (200 m, 500 m, 1000 m, 5000 m, and marathon races), women canoe is a very recent event. The first official world championship where women participated in canoe was in 2010, and it was not until Tokyo 2020 that they were included in the Olympic program, 84 years after the first time canoeing was introduced into the Summer Olympic Games.

Successful canoeing performance relies on a mix of anthropometrical, physiological, biomechanical, neuromuscular, psychological, and nutritional factors, with differences between sexes and modalities [1]. Identifying and understanding the training conditions that influence canoeists' performances is essential in using the appropriate battery of tests where the results can aid in properly guiding their training programs, optimizing sports performance, detecting talented athletes, and determining the risk of injury. To date, this work is lacking.

Sex differences in athletic performance must be addressed in a multifactorial manner, as they are influenced by inherent biological and anatomical differences, as well as environmental forces that shape culture and affect sports participation, development, and training [2]. These differences in performance have been studied in various sports, which requires a deep understanding of the physiological, psychological, social, behavioral, and environmental factors involved [3]. However, as far as we know, canoeing research has been based primarily on male canoeists. The lack of women canoeing research has caused many coaches to rely on training methods and reference values for men, preventing real knowledge of their characteristics and, therefore, from being able to develop their maximum performance.

Several authors have previously highlighted differences between performance levels (international, national, and novice) in kayakers' paddling kinematics such as reduced stroke amplitude, trunk rotation, leg motion [4–6], or lower specific trunk and lower limb forces in less skilled athletes [7,8]. However, from our knowledge, performance differences that may exist within the canoeing elite level have not been addressed. Not every national team athlete manages to win a medal in a major international event. Therefore, at this high level of performance, establishing differences between being a finalist at a major international event of the sport or winning a medal could be of great interest.

The use of technological devices that allow for measuring and controlling training load in athletes has increased significantly in recent years. On one hand, tensiomyography (TMG) is a non-invasive mechanomyographic diagnostic tool that uses controlled electrical stimulation to assess the contractile properties and muscle tone of superficial muscles under isometric conditions. This stimulation results in a displacement–time curve from which parameters such as maximum radial displacement, contraction time, sustainment time, delay time, or recovery, among others, are obtained [9]. These indicators provide very useful information about an athlete's muscle properties.

On the other hand, in sports performance, the measurement of parameters such as strength, speed, power, work, and impulse are frequently addressed individually to assess sporting gestures or actions. Currently, there are multi-joint isokinetic dynamometers that allow all these variables to be assessed at the same time with a single device [10]. Within this technology, the most advanced models are functional electromechanical dynamometers (FEMDs). They emerge as a new instrument that allows for performing a wide variety of movements and assessing parameters derived from linear isokinetic velocities, dynamic modes (tonic, kinetic, elastic, inertial, and conical), and static modes (isometric and vibratory). This device is not only a valid and reliable evaluation tool [11] but it can also be very useful as training equipment through constant and/or variable resistance/speed [12]. When applied to high-performance athletes, the use of this technology can be useful as a diagnostic tool, providing relevant information for prescribing physical exercise, performance improvement, and injury prevention/recovery [13]. These tools are becoming relevant for athletes with complex technical motor patterns, such as canoeists due to their one-side stroke from a kneeling position over an unstable aquatic environment. The force transmitted to the stroke for propulsion has an important influence on performance [1,14,15]. This propulsion occurs once the paddler's blade comes into contact with the water (from catch to exit) [16]. Nevertheless, leg action in a canoe when there is no water contact during the aerial phase (from exit to next stroke catch) should not be underestimated due to its contribution to reducing speed loss [17].

In this sense, there is no work in the literature assessing elite and world-class canoeists, both female and male, using this combination of TMG and FEMD technologies. We believe that the inclusion of women canoe in the Olympic Games reflects the growth of this modality. Females must be studied in depth to optimize performance by focusing their training programs appropriately and improving the talent detection and even injury prevention of this population. Therefore, the aim of this study was to explore sex differences in contractile properties using TMG, range of motion (ROM), strength, and canoe-specific FEMD performance between female and male elite canoeists and establish performance differences between medalists and non-medalists during an official international championship.

2. Materials and Methods

2.1. Study Design

A cross-sectional comparative design was carried out following an associative strategy to find out the existence of sex and international performance level differences in contractile properties, range of motion (ROM), strength, and FEMD performance between female and male elite canoeists.

2.2. Participants

Twelve male and nine female canoeists from the Spanish and Portuguese national canoe teams composed our sample. Although all recruited athletes are the best in their respective countries, at an international level, there are subtle differences in performance. Therefore, we used Mckay et al.'s [18] performance classification to classify our canoeist as Tier 5 (World Class—medalist at a major international event) and Tier 4 (Elite/International Level—finalist at a major event). However, both groups are similar in terms of body composition since no differences were shown in baseline mean values between Tier 5 and Tier 4 (see Table 1).

Table 1. Canoeists' body composition characteristics based on Mckay et al.'s (2022) performance classification.

	Men			**Women**		
	Tier 5 (*n* = 9)	**Tier 4 (*n* = 3)**	**Total (*n* = 12)**	**Tier 5 (*n* = 4)**	**Tier 4 (*n* = 5)**	**Total (*n* = 9)**
Age	23.11 ± 5.08 (19–36)	17.33 ± 1.55 (16–18)	21.45 ± 5.28 (16–36)	19.00 ± 1.41 (18–21)	16.80 ± 1.92 (15–20)	17.78 ± 1.99 (15–21)
Height	178.93 ± 7.28 (170.0–190.0)	175.73 ± 8.22 (172.0–181.7)	178.06 ± 6.69 (170.0–190.0)	159.62 ± 4.21 (154.5–164.5)	163.60 ± 9.38 (153.0–176.5)	161.83 ± 7.42 (153.0–176.5)
Weight	79.18 ± 6.90 (70.10–87.30)	70.30 ± 8.23 (65.40–79.80)	76.96 ± 7.81 (65.40–87.30)	60.87 ± 6.34 (55.10–67.80)	63.00 ± 8.21 (55.80–74.90)	62.06 ± 7.07 (55.10–74.90)
Body Fat	12.58 ± 2.53 (7.30–14.70)	10.67 ± 0.55 (10.30–11.30)	12.10 ± 2.33 (7.30–14.70)	21.25 ± 1.49 (19.40–22.70)	19.89 ± 2.88 (16.00–23.60)	20.49 ± 2.35 (16.00–23.60)
Muscle mass	65.83 ± 5.22 (57.80–71.50)	59.67 ± 7.23 (55.10–68.00)	64.29 ± 6.09 (55.10–71.50)	45.37 ± 4.15 (41.10–50.10)	47.60 ± 6.44 (41.60–57.90)	46.61 ± 5.35 (41.10–57.90)
Bone mass	3.43 ± 0.27 (3.00–3.70)	3.13 ± 0.32 (2.90–3.50)	3.36 ± 0.29 (2.90–3.70)	2.45 ± 0.21 (2.20–2.70)	2.54 ± 0.34 (2.20–3.10)	2.50 ± 0.28 (2.20–3.10)
BMI	24.61 ± 1.13 (22.4–26.4)	22.63 ± 1.29 (21.7–24.1)	24.12 ± 1.42 (21.7–26.4)	23.77 ± 1.83 (21.8–26.8)	23.46 ± 1.68 (20.9–25.4)	23.60 ± 1.64 (20.9–26.2)
Water	63.39 ± 2.38 (60.70–68.20)	64.37 ± 1.03 (63.50–65.50)	63.63 ± 2.12 (60.70–68.20)	60.25 ± 1.72 (58.20–62.40)	61.46 ± 2.13 (59.90–65.20)	60.92 ± 1.95 (58.20–65.20)

Values are presented as mean ± standard deviation (minimum and maximum values). Age is in years; height in cm; weight in kg; body fat in %; muscle mass in kg; bone mass in kg; BMI (body mass index); water in %. Body composition was analyzed through a bioelectrical impedance analysis (Tanita BC-601 Segment, Tanita Corporation, Tokyo Japan).

All participants and their parents or legal guardians for minors were informed of the project's background, the procedures to be followed, their purposes, and a description of the expected benefits. Each athlete signed an informed consent form. The study protocol was conducted in accordance with the guidelines of the Declaration of Helsinki for Biomedical Research in Humans (64th World Medical Assembly 2013) and was previously approved by the Ethical Research Committee of the University of Vigo.

2.3. Procedure

Canoeists were evaluated within the competitive period to obtain optimal physical fitness and in recovery microcycles to avoid accumulated fatigue that could affect testing performance. Because of the sample size and the different locations/countries of the training groups, data collection was carried out at different moments depending on the planning of each training group. The first round of data collection was carried out in March before Spanish and Portuguese Sprint trials, the second one in May before ICF World Cup I and II, and the final one between June and July prior to the ECA Junior and U23 Sprint European Championships and European Games.

The testing protocol consisted of a muscle contractile properties assessment using TMG, an upper and lower body ROM and explosive strength assessment, and a performance assessment using canoe-specific FEMD. All tests were carried out in the same order (1° TMG, 2° ROM, 3° Strength, 4° FEMD) and conducted by the same experienced researchers, especially in TMG and ROM assessments since they are very sensitive tools where the reliability depends on the evaluator (researchers' previous reliability values for TMG: ICC between 0.91 and 0.99 and CV between 2.6 and 3.3%; and ROM: ICC between 0.92 and 0.98 and CV between 1.3 and 9.1%).

2.3.1. Muscle-Tendon Contractile Properties

Tensiomyography was used to measure the radial muscle belly displacement of the main muscles involved in the canoeist stroke: biceps femoris (BF), deltoid (DE), erector spinae (ES), latissimus dorsi (LD), pectoralis mayors (PM), rectus femoris (RF), semitendinosus (ST), tibialis anterior (TA), and trapezius (TZ). Measurements were carried out on both side muscles following García-García et al.'s [9,19,20] protocol. The digital displacement transducer sensor (GK 30, Panoptik d.o.o., Ljubljana, Slovenia) was set perpendicular to the thickest part of the muscle belly. The self-adhesive electrodes (5 × 5 cm, Cefar-Compex Medical AB Co., Ltd., Malmö, Sweden) were symmetrically placed 5 cm from the sensor in accordance with Perotto et al.'s [21] anatomic guidelines (see Figure 1). An incremental electrical stimulation was applied starting at an initial current amplitude of 30 mA and progressively increased in 10 mA steps until reaching 110 mA (maximal stimulator output). The electrical stimulus was produced by a TMG-S2 (EMF-FURLAN & Co. d.o.o., Ljubljana, Slovenia) stimulator. Each measurement recorded the following parameters: maximum radial muscle belly displacement (Dm) in mm, contraction time (Tc) as the time in ms from 10% to 90% of Dm, and radial displacement velocity (Vrd) obtained as the rate ($mm \cdot s^{-1}$) between the radial displacement occurring during the Tc obtained using the formula $(0.8 \times Dm/Tc) \times 1000$. The curve with the greater Dm was selected for further analysis.

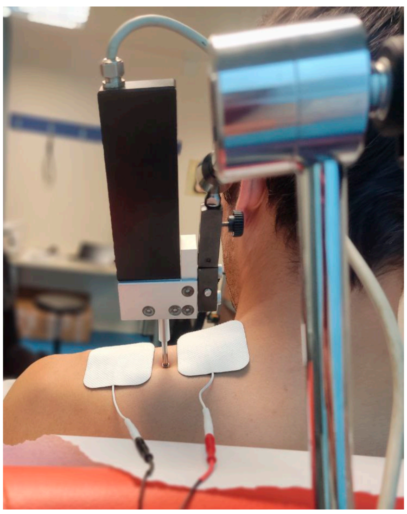

Figure 1. Trapezius TMG assessment.

2.3.2. Range of Motion

The Active Knee Extension (AKE) test was used to assess hamstring flexibility. This test is based on angular measurements that record knee extension achieved with 90° hip flexion. The AKE test was carried out on both limbs following Gajdosik and Lusin's [22] protocol. The goniometer fulcrum was placed at the lateral epicondyle, the stationary arm parallel to the thigh pointing to the greater trochanter, and the moving arm parallel to the leg aligned with the lateral malleoli. Two expert evaluators conducted this test, one in charge of recording data with a digital goniometer (Baseline Absolute Axis 360°, Fabrication Enterprises, Inc., White Plains, NY, USA) and the other one ensuring no compensatory movements from the canoeists during the measurement. Three measurements were carried out with each leg, using the mean value for analysis.

Shoulder external rotation (ER) and internal rotation (IR) tests were performed following Wilk et al.'s [23] protocol. Paddlers laid supine on a stretcher with the shoulder at 90° of with 90° of elbow flexion. The center of rotation of the digital goniometer (Baseline Absolute Axis 360°, Fabrication Enterprises, Inc., White Plains, NY, USA) was placed over the tip of the olecranon while the moving arm was positioned along the length of the ulna, aligned with the ulnar styloid process. The stationary arm was positioned inferiorly and perpendicular to the ground, using the bubble level to ensure proper alignment. Shoulder ER was carried out by asking the athletes to rotate their arm backward as far as possible so that their palm was facing the ceiling. Shoulder IR was performed in the same position but participants were asked to rotate their arm forward as far as possible so that their palm was facing the floor. Three measurements were carried out with each arm, using the mean value for analysis.

Shoulder flexion ROM (FLEX) was measured by asking the paddlers to raise their arm straight overhead as far as possible while keeping their elbows straight [24]. The stationary arm of the digital goniometer was positioned parallel to the midline of the thorax while the moving arm was aligned with the shaft of the humerus and lateral epicondyle. Three measurements were carried out with each arm, using the mean value for analysis.

The Y-Balance Upper Quarter test (YBT-UQ) was used to assess the stability and mobility of the upper extremities. All athletes started the test with their right hand as the stance hand, which was aligned on the platform with the thumb behind the starting line. The test consisted of moving the three wooden blocks of the Y-Balance Test Kit (Functional Movement System, Inc., Danville, CA, USA) in the medial (YBT-UQ_{med}), inferolateral (YBT-UQ_{inf}), and superolateral (YBT-UQ_{sup}) directions as far as possible with the free hand while maintaining a push-up position with shoes off. An attempt was considered a failure when Williamson et al.'s [25] fault criteria were observed: failure to maintain a unilateral stance, failure to maintain reach-hand contact, use of reach indicator for stance support, failure to return the reach hand to the starting position, or lifting of either foot of the floor. The maximum reach distance for each reach direction was normalized by dividing it by the upper limb length. Upper limb length was measured with a tape measure (Seca 203, Hamburg, Germany) from the C7 vertebrae to the end of the third finger of the hand with the shoulder at 90°, elbow extended, and wrist in a neutral position [26]. Two measurements were carried out with each arm, using the mean value for analysis. To compare both limbs, these measures were normalized using the following formula:

$$\text{(distance obtained/relative length of the limb)} \times 1000 \quad (1)$$

2.3.3. Strength Tests

An explosive strength test using a horizontal Leg Press (RS-1403 Leg Press ROC-IT line; HOIST, Poway, CA, USA) and a one-side canoe position cable row (Cable Colum Signature Series, LifeFitness, Illinois, USA) simulating the canoe stroke was performed after each canoeist's individual warm-up. Mean velocity (V_m) and maximum velocity (V_{max}) in m/s, time in s to until each V_{max} (T_{vmax}), average power (P_m) and maximum power (P_{max}) in W, and time in s to reach P_{max} (T_{pmax}) were recorded using a Linear Encoder

(Chronojump Boscosystem, Barcelona, Spain) and Chronojump software (version 1.7.0 for Windows; Chronojump Boscosystem). Several authors have studied their validity and reliability (ICC = 0.95–0.988) to measure the speed of movement and estimate power [27].

The horizontal Leg Press test was performed with one-leg support and a relative load in kg corresponding to 50% of the canoeist's body weight. The movement consisted of a full leg extension starting from hip and knee flexion. Two isolated repetitions were performed with each leg with a recovery time between repetitions at the decision of the subject. The best attempt was retained for further analysis.

The one-side canoe position cable row was performed in the canoe-specific kneeling position and by attaching the paddle shaft to the cable column (Cable Column Signature Series, LifeFitness, Rosemont, IL, USA). The movement consisted of a pull simulating the water stroke phase (from the catch to extraction) with a half-body-weight load. Two isolated repetitions were performed, with a recovery time between repetitions at the free decision of the subject [14]. The best attempt was retained for further analysis.

The one repetition maximum (1RM) in bench press and bench pull was provided by the canoeist's coaches. These exercises are widely used in canoeing [1] and are constantly updated to set the intensity (%1RM) of strength training sessions.

2.3.4. Canoe-Specific FEMD Performance

Maximum isometric strength was assessed with a validated FEMD (Dynasystem Research, SYMOTECH, Granada, Spain), which presents a precision of 3 mm for displacement, 100 g for a sensed load, and a sampling frequency of 1000 Hz (CV < 10% ICC > 0.86) [11,28]. Canoeists were positioned in their kneeling-specific paddling position on a canoe ergometer (Dansprint PRO Canoe Ergometer, Hvidovre, Denmark) (see Figure 2). The ergometer's shaft was adapted to the FEMD cable to maintain the greatest similarity to on-water and canoe ergometer stroke. Before the beginning of the test, each paddler set up the ergometer in their most comfortable position, simulating their training daily canoe setup. The FEMD cable was lengthened to the stroke pull position where the maximum force is applied, which corresponds to when the shaft is set perpendicularly [29]. Once the paddler was settled, they performed a maximum isometric contraction of five seconds following Rodríguez-Perea et al.'s [28] protocol. Canoeists only performed the test on the paddling side, obtaining the average (F_m) and peak force (F_{peak}) for analysis.

Figure 2. Canoe-specific isometric assessment using FEMD.

Maintaining the ergometer setup of the isometric test, canoeists proceeded to carry out a maximal incremental dynamometer test. The FEMD (Dynasystem Research, SYMOTECH, Granada, Spain) was configured in a tonic mode so that the load was increased by 3 kg with each stroke. The range of motion for the pull was individually set to simulate canoe–water contact positions defined by McDonnell et al. [16]. Each repetition simulated the water phase of a stroke, starting from the entry of the blade in the water (the catch) and finishing at the blade exit point (extraction) (see Figure 3). Therefore, it was important that each canoeist settled into the most comfortable cable length of the FEMD to better simulate the stroke water phase. The test concluded when the canoeist was not able to achieve a complete stroke due to the FEMD resistance. The test was only performed on the canoeists' stroke side, retaining the number of strokes ($N_{strokes}$), maximum power (P_{max}), and peak force (F_{peak}) for analysis.

(**a**) (**b**)

Figure 3. Stroke simulation in the canoe-specific maximal incremental FEMD test. (**a**) Catch position; (**b**) extraction position.

2.4. Statistical Analysis

The normal and lineal distributions of the data were verified by applying the Shapiro–Wilk test, in conjunction with the Lilliefors test. A two-way ANOVA and Tuckey post-hoc test were used to analyze whether the canoeist's international performance level (medal winner at an official international event vs. non medal winner) and sex significantly affected muscle contractile properties, ROM, strength, and canoe-specific FEMD performance. The effect sizes in two-way ANOVA were reported as partial eta square (η_p^2) and interpreted as small (0.02), moderate (0.06), or large (0.14) [30]. All analyses were performed using the Statistics Package for the Social Sciences (SPSS version 25.0 for Windows, SPSS Inc., Chicago, IL, USA). Effect sizes (*p*-value) greater than 0.05 were considered statistically significant.

3. Results

The contractile properties of the main muscle involved in the canoe stroke showed a *sex* effect in the LD and ST muscles of the stroke side with a large effect size. Males presented 34.6% higher Tc (F = 10.062; p = 0.006; η_p^2 = 0.372) and 27.3% Dm (F = 7.709; p = 0.017; η_p^2 = 0.292) in the LD muscle than female canoeists. In addition, they also presented 21.1% higher Tc in the ST muscle (F = 9.345; p = 0.007; η_p^2 = 0.355). On the other hand, performance level had a significant effect on the BF, ES, and TZ muscles with a large effect size. Males classified as Tier 5 showed 25.2% greater Vrd in the BF muscle of the stroke side (F = 4.467; p = 0.05; η_p^2 = 0.208), with large effect size, 25% greater Vrd in the ES muscle of the non-stroke side (F = 4.441; p = 0.05; η_p^2 = 0.206), and 33% greater Vrd in the TZ muscle on the non-stroke side (F = 5.379; p = 0.033; η_p^2 = 0.240) than Tier 4 canoeists (see Table 2).

In addition, the *sex x international performance level* interaction had a significant effect with a large effect size in the LD (stroke side Dm: F = 5.521; p = 0.031; η_p^2 = 0.245), PM (non-stroke side Tc: F = 7.724; p = 0.013; η_p^2 = 0.312), and TA (non-stroke side Vrd: F = 6.048; p = 0.025; η_p^2 = 0.262) muscles (see Table 2).

Table 2. Sex and performance differences in TMG parameters characteristics of world-class and elite international canoeists.

		Side	Men	Women	Diff (%)	Tier 5	Tier 4	Diff (%)
BF	Tc	Stroke	37.29 ± 4.51	39.48 ± 4.54	5.87	32.12 ± 4.06	44.64 ± 4.94	38.97
		Non-Stroke	44.16 ± 3.81	37.99 ± 3.83	13.97	39.91 ± 3.43	42.24 ± 4.17	5.83
	Dm	Stroke	7.75 ± 0.77	9.72 ± 0.77	25.41	8.60 ± 0.69	8.88 ± 0.84	3.25
		Non-Stroke	9.69 ± 0.84	9.03 ± 0.84	6.81	9.76 ± 0.75	8.95 ± 0.92	8.29
	Vrd	Stroke	171.56 ± 18.62	214.83 ± 18.74	25.22 *	221.11 ± 16.78	165.27 ± 20.40	25.25 *
		Non-Stroke	183.37 ± 19.36	194.40 ± 19.48	6.01	210.39 ± 17.45	167.38 ± 21.21	20.44
DE	Tc	Stroke	15.40 ± 0.96	15.59 ± 0.97	1.23	15.23 ± 0.87	15.76 ± 1.05	3.47
		Non-Stroke	15.95 ± 3.93	20.77 ± 3.95	30.21	15.61 ± 3.54	21.11 ± 4.30	35.23
	Dm	Stroke	3.73 ± 0.39	3.12 ± 0.39	16.35	3.36 ± 0.35	3.49 ± 0.43	3.86
		Non-Stroke	4.06 ± 0.41	3.59 ± 0.41	11.57	3.62 ± 0.37	4.03 ± 0.45	11.32
	Vrd	Stroke	197.02 ± 22.85	164.92 ± 22.99	16.29	177.97 ± 20.60	183.98 ± 25.03	3.37
		Non-Stroke	202.94 ± 22.35	167.63 ± 22.49	17.39	185.51 ± 20.15	185.06 ± 24.48	0.24
ES	Tc	Stroke	17.24 ± 1.28	15.32 ± 1.29	11.13	15.73 ± 1.15	16.82 ± 1.40	6.92
		Non-Stroke	16.77 ± 0.92	15.00 ± 0.92	10.55	15.00 ± 0.83	16.77 ± 1.01	11.8
	Dm	Stroke	5.83 ± 0.65	4.42 ± 0.66	24.18	5.34 ± 0.59	4.90 ± 0.72	8.23
		Non-Stroke	6.07 ± 0.63	5.58 ± 0.64	8.07	6.33 ± 0.57	5.32 ± 0.69	15.95
	Vrd	Stroke	277.73 ± 32.94	232.88 ± 33.15	16.14	277.99 ± 29.70	232.63 ± 36.09	16.31
		Non-Stroke	295.34 ± 28.60	299.78 ± 28.78	1.50	340.22 ± 25.78	254.90 ± 31.33	25.07 *
LD	Tc	Stroke	36.10 ± 2.77	23.60 ± 2.79	34.62 *	28.69 ± 2.50	31.00 ± 3.04	8.05
		Non-Stroke	28.52 ± 2.66	21.65 ± 2.68	24.08	28.49 ± 2.40	21.68 ± 2.91	23.90
	Dm	Stroke	10.31 ± 0.75	7.49 ± 0.75	27.35 *	8.58 ± 0.67	9.23 ± 0.82	7.57
		Non-Stroke	8.61 ± 1.16	8.25 ± 1.17	4.18	9.71 ± 1.05	7.16 ± 1.27	26.26
	Vrd	Stroke	247.55 ± 31.12	263.70 ± 31.31	6.52	261.24 ± 28.05	250.01 ± 34.09	4.29
		Non-Stroke	251.28 ± 49.05	324.72 ± 49.36	29.22	304.87 ± 44.21	271.141 ± 53.73	11.06
PM	Tc	Stroke	21.44 ± 0.88	20.25 ± 0.88	5.55	20.48 ± 0.79	21.21 ± 0.96	3.56
		Non-Stroke	21.58 ± 1.11	21.22 ± 1.12	1.66	21.16 ± 1.00	21.64 ± 1.22	2.26
	Dm	Stroke	8.56 ± 1.02	9.20 ± 1.03	7.47	9.78 ± 0.92	7.98 ± 1.12	18.40
		Non-Stroke	7.29 ± 0.98	7.85 ± 0.99	7.68	7.50 ± 0.88	7.64 ± 1.07	1.86
	Vrd	Stroke	317.60 ± 34.74	361.74 ± 34.96	13.89	381.75 ± 31.31	297.59 ± 38.06	22.04
		Non-Stroke	272.47 ± 34.72	293.93 ± 34.93	7.87	286.77 ± 31.29	279.64 ± 38.03	2.48
RF	Tc	Stroke	26.80 ± 1.95	26.24 ± 1.96	2.08	25.72 ± 1.76	27.32 ± 2.14	6.22
		Non-Stroke	25.38 ± 1.17	24.99 ± 1.18	1.53	26.01 ± 1.06	24.36 ± 1.28	6.34
	Dm	Stroke	8.09 ± 0.85	7.66 ± 0.85	5.31	8.30 ± 0.77	7.45 ± 0.93	10.24
		Non-Stroke	7.64 ± 0.60	7.44 ± 0.61	2.61	7.75 ± 0.54	7.34 ± 0.66	5.29
	Vrd	Stroke	250.56 ± 27.33	239.53 ± 27.50	4.40	262.43 ± 24.64	227.66 ± 29.94	13.24
		Non-Stroke	243.97 ± 24.68	245.54 ± 24.83	0.64	243.53 ± 22.25	245.98 ± 27.04	1.00

Table 2. *Cont.*

		Side	Men	Women	Diff (%)	Tier 5	Tier 4	Diff (%)
ST	Tc	Stroke	41.82 ± 2.04	32.98 ± 2.05	21.13 *	34.90 ± 1.83	39.90 ± 2.23	14.32
		Non-Stroke	43.37 ± 2.25	40.01 ± 2.26	7.74	43.48 ± 2.02	39.91 ± 2.46	8.21
	Dm	Stroke	10.25 ± 0.76	9.18 ± 0.76	10.43	9.14 ± 0.68	10.29 ± 0.83	12.58
		Non-Stroke	9.74 ± 1.03	9.75 ± 1.04	0.10	10.20 ± 0.92	9.28 ± 1.12	9.01
	Vrd	Stroke	201.43 ± 18.55	221.04 ± 18.66	9.73	212.53 ± 16.72	209.95 ± 20.32	1.21
		Non-Stroke	180.95 ± 18.08	194.65 ± 18.19	7.57	188.87 ± 16.30	186.73 ± 19.81	1.13
TA	Tc	Stroke	40.34 ± 5.52	27.80 ± 5.56	31.08 *	28.03 ± 4.98	40.11 ± 6.05	43.09
		Non-Stroke	36.00 ± 5.80	38.61 ± 5.83	7.25	33.63 ± 5.23	40.98 ± 6.35	21.85
	Dm	Stroke	4.51 ± 0.55	4.08 ± 0.55	9.53	3.90 ± 0.50	4.69 ± 0.60	20.25
		Non-Stroke	4.23 ± 0.48	4.23 ± 0.49	0	3.55 ± 0.43	4.92 ± 0.53	38.59
	Vrd	Stroke	102.45 ± 11.80	126.13 ± 11.87	23.11	128.25 ± 10.64	100.33 ± 12.93	21.76
		Non-Stroke	108.18 ± 11.24	99.59 ± 11.31	7.94	97.61 ± 10.13	110.16 ± 12.31	12.85
TZ	Tc	Stroke	32.24 ± 5.85	30.02 ± 5.79	6.88	28.22 ± 5.29	34.05 ± 6.31	20.65
		Non-Stroke	40.16 ± 6.87	27.96 ± 6.91	30.37	28.92 ± 6.19	39.20 ± 7.53	35.54
	Dm	Stroke	7.53 ± 0.93	6.77 ± 0.92	10.09	7.06 ± 0.84	7.23 ± 1.00	2.40
		Non-Stroke	7.74 ± 0.97	7.07 ± 0.97	8.65	8.01 ± 0.87	6.80 ± 1.06	15.10
	Vrd	Stroke	204.50 ± 20.32	200.87 ± 20.13	0.01	217.38 ± 18.38	187.99 ± 21.92	13.52
		Non-Stroke	179.94 ± 24.05	219.37 ± 24.20	21.91	239.23 ± 21.68	160.08 ± 26.35	33.08 *

Values are presented as mean ± SD (standard deviation). Tier 5 (medalists at a major international event); Tier 4 (finalists at a major event). BF (Biceps Femoris), DE (Deltoid), ES (Erector Spinae), LD (Latissimus Dorsi), PM (Pectoralis Mayors), RF (Rectus Femoris), ST (Semitendinosus), TA (Tibialis Anterior), TZ (Trapezius), Tc (contraction time in ms), Dm (maximum radial muscle belly displacement in mm), Vrd (radial displacement velocity in $mm \cdot s^{-1}$), * ($p < 0.05$).

Regarding ROM assessments, canoeists' performance levels showed no significant effects, with only a *sex* effect on the YBT-UQ in the medial direction of the stroke side ($F = 6.349$; $p = 0.023$; $\eta_p^2 = 0.284$), where male canoeists showed 5.64% greater mobility than female canoeists. The *sex x international performance level* interaction had a significant effect with a large effect size on the shoulder FLEX of the non-stroke side ($F = 8.676$; $p = 0.009$; $\eta_p^2 = 0.338$), the YBT-UQ medial direction of the stroke side ($F = 9.210$; $p = 0.008$; $\eta_p^2 = 0.365$), and the YBT-UQ inferolateral direction of the non-stroke side ($F = 5.638$; $p = 0.030$; $\eta_p^2 = 0.261$) (see Table 3).

Focusing on strength assessments, canoeists' *international performance level* showed a significant great effect on Leg Press T_{vmax} and T_{pmax} on the stroke side ($F = 9.973$; $p = 0.006$; $\eta_p^2 = 0.384$) and the non-stroke side ($F = 7.692$; $p = 0.014$; $\eta_p^2 = 0.325$), with Tier 5 canoeists' achieving their maximum speed and power 29.8% and 19.4%, respectively, faster than the Tier 4 canoeists. On the other hand, male canoeists displayed a higher Fmax on both sides than female canoeists (25.9%; $F = 6.533$; $p = 0.021$; $\eta_p^2 = 0.290$ and 28.8; $F = 9.572$; $p = 0.007$; $\eta_p^2 = 0.374$, respectively) (see Table 4).

The canoe-position cable row showed a *sex* effect on P_m ($F = 14.113$; $p = 0.002$; $\eta_p^2 = 0.469$) and P_{max} ($F = 20.177$; $p = 0.000$; $\eta_p^2 = 0.558$), with large effect size. Male canoeists achieved 47.9% and 45.9% greater P_m and P_{max}, respectively, than female canoeists. *International performance level* only had a great effect on the P_m ($F = 4.685$; $p = 0.046$; $\eta p^2 = 0.226$), with Tier 4 canoeists achieving 30.7% greater P_m than Tier 5 canoeists. The 1RM showed a large *sex* effect in bench press ($F = 21.595$; $p = 0.000$; $\eta_p^2 = 0.547$) and bench pull performances ($F = 22.394$; $p = 0.000$; $\eta_p^2 = 0.583$). Male canoeists showed 37.2% and 17.7% greater maximum strength than female canoeists, respectively (see Table 4).

Table 3. Sex and performance differences in ROM characteristics of world-class and elite canoeists.

	Side	Men	Women	Diff (%)	Tier 5	Tier 4	Diff (%)
ER	Stroke	80.28 ± 3.91	81.29 ± 3.94	1.25	80.32 ± 3.53	81.25 ± 4.29	1.15
	Non-Stroke	73.55 ± 3.90	82.80 ± 3.92	12.57	79.01 ± 3.51	77.33 ± 4.27	2.12
IR	Stroke	64.36 ± 4.35	71.26 ± 4.38	10.72	66.69 ± 3.92	68.93 ± 4.77	3.35
	Non-Stroke	64.26 ± 4.50	69.09 ± 4.53	7.51	63.66 ± 4.05	69.69 ± 4.93	9.47
FLEX	Stroke	166.00 ± 2.88	165.01 ± 2.90	0.59	162.30 ± 2.60	168.71 ± 3.16	3.94
	Non-Stroke	169.37 ± 3.08	163.35 ± 3.10	3.55	161.95 ± 2.78	170.77 ± 3.38	5.44
YBT-UQ_{med}	Stroke	101.44 ± 1.61	95.71 ± 1.60	5.64 *	98.36 ± 1.46	98.79 ± 1.74	0.43
	Non-Stroke	98.51 ± 2.22	96.18 ± 2.20	2.36	96.99 ± 2.00	97.70 ± 2.39	0.73
YBT-UQ_{sup}	Stroke	68.57 ± 3.22	72.95 ± 3.19	6.38	67.20 ± 2.91	74.33 ± 3.47	10.61
	Non-Stroke	67.82 ± 3.31	70.42 ± 3.28	3.83	64.19 ± 2.99	74.05 ± 3.57	15.36 *
YBT-UQ_{inf}	Stroke	92.99 ± 3,12	92.30 ± 3.09	0.74	92.48 ± 2.82	92.81 ± 3.36	0.35
	Non-Stroke	92.69 ± 3.06	91.11 ± 3.03	1.70	90.48 ± 2.77	93.31 ± 3.30	3.12
AKE	Stroke	148.93 ± 4.03	156.17 ± 4.06	4.86	148.17 ± 3.63	156.92 ± 4.42	5.90
	Non-Stroke	155.55 ± 3.41	162.03 ± 3.43	4.16	155.52 ± 3.07	162.05 ± 3.74	4.19

Values are presented as mean ± SD (standard deviation). Tier 5 (medalists at a major international event); Tier 4 (finalists at a major event). ER (shoulder external rotation in °), IR (shoulder internal rotation in °), FLEX (shoulder flexion in °), YBT-UQ_{med} (Y-Balance Test in the medial direction), YBT-UQ_{sup} (Y-Balance Test in the superolateral direction), YBT-UQ_{inf} (Y-Balance Test in the inferolateral direction), AKE (Active Knee Extension in °), * ($p < 0.05$).

Table 4. Sex and performance differences in strength characteristics of world-class and elite canoeists.

		Men	Women	Diff (%)	Tier 5	Tier 4	Diff (%)
Leg Press Stroke Side	V_m	0.62 ± 0.10	0.74 ± 0.09	19.35	0.76 ± 0.09	0.60 ± 0.10	21.05
	V_{max}	1.18 ± 0.19	1.42 ± 0.18	20.33	1.39 ± 0.17	1.21 ± 0.20	12.94
	T_{vmax}	518.85 ± 40.25	467.50 ± 39.89	0.09	403.68 ± 36.41	582.66 ± 43.42	44.33 *
	P_m	256.84 ± 46.08	257.70 ± 45.66	0.33	291.96 ± 41.68	222.58 ± 49.71	23.76
	P_{max}	583.24 ± 116.41	615.53 ± 115.35	5.53	661.24 ± 105.30	537.54 ± 125.58	18.70
	T_{pmax}	460.47 ± 40.72	420.05 ± 40.35	8.77	350.56 ± 36.83	529.96 ± 43.93	51.17
	F_m	402.05 ± 23.26	345.74 ± 23.04	14.00	391.04 ± 21.04	356.75 ± 25.09	8.76
	F_{max}	659.70 ± 47.63	488.29 ± 47.20	25.98 *	654.45 ± 43.09	493.54 ± 51.38	24.58 *
Leg Press Non-Stroke Side	V_m	0.66 ± 0.10	0.77 ± 0.10	16.66	0.79 ± 0.09	0.64 ± 0.11	18.98
	V_{max}	1.20 ± 0.18	1.42 ± 0.18	18.33	1.40 ± 0.16	1.23 ± 0.19	12.14
	T_{vmax}	416.00 ± 21.64	424.50 ± 21.44	2.04	378.00 ± 19.57	462.50 ± 23.34	22.35 *
	P_m	271.31 ± 45.84	256.97 ± 45.42	5.28	295.72 ± 41.46	232.55 ± 49.45	21.36
	P_{max}	615.60 ± 116.63	614.08 ± 115.56	0.24	668.18 ± 105.49	561.50 ± 125.81	15.96
	T_{pmax}	359.18 ± 24.03	366.72 ± 23.81	2.09	322.31 ± 21.74	403.60 ± 25.92	25.22 *
	F_m	402.64 ± 22.36	336.18 ± 22.16	16.37 *	384.52 ± 20.22	354.30 ± 24.12	7.85
	F_{max}	692.87 ± 45.94	492.72 ± 45.52	28.88 *	674.71 ± 41.55	510.88 ± 49.55	24.28 *
Canoe position cable row	P_m	389.67 ± 35.32	202.86 ± 35.00	47.94 *	242.45 ± 31.95	350.08 ± 38.10	86.82 *
	P_{max}	627.10 ± 45.57	338.92 ± 45.15	45.95 **	433.63 ± 41.22	532.38 ± 49.16	22.77
1RM	Bench Press	112.37 ± 6.39	70.55 ± 6.33	37.21 *	100.37 ± 5.78	82.55 ± 6.89	17.75
	Bench Pull	107.83 ± 5.07	74.05 ± 5.02	17.75 *	97.25 ± 4.58	84.63 ± 5.47	12.97

Values are presented as mean ± SD (standard deviation). Tier 5 (medalists at a major international event); Tier 4 (finalists at a major event). 1RM (1 repetition maximum in Kg),V_m (average velocity in m/s), V_{max} (maximum velocity in m/s), T_{vmax} (time until reaching Vmax in s), P_m (average power in W), P_{max} (maximum power in W), T_{pmax} (time until reaching Pmax in s), F_m (average force in N), F_{max} (maximum force in N), SD (standard deviation), ** ($p \leq 0.001$); * ($p < 0.05$).

Regarding the canoe dynamometry assessments, the performance of the specific isometric test showed a great *sex* effect on F_m ($F = 13.778$; $p = 0.002$; $\eta_p^2 = 0.448$) and F_{peak} ($F = 14.773$; $p = 0.001$; $\eta_p^2 = 0.465$). Male canoeists achieved 29.5% and 31.5% greater F_m and F_{peak} than female canoeists. Similarly for the maximal incremental test, N_{reps} ($F = 62.326$; $p = 0.000$; $\eta_p^2 = 0.786$), F_{peak} ($F = 30.690$; $p = 0.000$; $\eta_p^2 = 0.644$), and P_{max} ($F = 15.902$;

p = 0.001; η_p^2 = 0.483) showed a great *sex* effect, with male canoeists achieving 38.1%, 36.9%, and 37.6%, higher performance than female canoeists, respectively. Furthermore, *international performance level* also showed a great effect on $N_{strokes}$ (F = 9.237; p = 0.007; η_p^2 = 0.352) and F_{peak} (F = 7.262; p = 0.015; η_p^2 = 0.299). Medalists achieved 16.6% and 19.7% higher performance in these variables compared to non-medalists, respectively. The *sex x performance level* interaction had a significant effect with a large effect size for $N_{strokes}$ (F = 7.374; p = 0.015; η_p^2 = 0.303), F_{peak} (F = 8.421; p = 0.010; η_p^2 = 0.331), and P_{max} (F = 4.930; p = 0.040; η_p^2 = 0.225) (see Table 5).

Table 5. Sex and performance differences in canoe-specific FEMD characteristics of world-class and elite canoeists.

		Men	Women	Diff (%)	Tier 5	Tier 4	Diff (%)
Isometric Test	F_m	52.86 ± 2.96	37.27 ± 2.97	29.49 *	48.58 ± 2.66	41.55 ± 3.24	14.47
	F_{peak}	60.83 ± 3.51	41.66 ± 3.53	31.51 **	55.92 ± 3.16	46.57 ± 3.85	16.72
Maximal Incremental Test	$N_{strokes}$	12.77 ± 0.43	7.90 ± 0.43	38.13 **	11.27 ± 0.39	9.40 ± 0.47	16.59 *
	P_m	182.96 ± 17.17	108.94 ± 17.27	40.45 *	160.53 ± 15.47	131.37 ± 18.80	18.16
	P_{max}	977.10 ± 65.10	608.80 ± 65.51	37.69 **	886.25 ± 58.68	699.65 ± 71.31	21.05 *
	F_m	17.27 ± 1.30	12.00 ± 1.31	30.51 *	15.42 ± 1.17	13.86 ± 1.43	10.11
	F_{peak}	51.33 ± 2.41	32.38 ± 2.42	36.91 **	46.46 ± 2.17	37.24 ± 2.64	19.84 *

Values are presented as mean ± SD (standard deviation). Tier 5 (medallist at a major international event); Tier 4 (finalist at a major event). F_m (average force in Kg), F_{peak} (peak force in Kg), $N_{strokes}$ (number of strokes), P_m (average power in N), P_{max} (maximum power in N), SD (standard deviation), ** ($p \leq 0.001$); * ($p < 0.05$).

4. Discussion

The main findings of this study show very few sex differences in muscle contractile properties and ROM. Focusing on canoeists' stroke side, males had a higher Tc in the LD and ST muscles and Dm in the LD muscle, and greater mobility in the medial direction of YBT-UQ than female canoeists. However, notable sex differences were shown in strength and FEMD performances. Male canoeists featured greater F_{max} in Leg Press, P_m and P_{max} in canoe position cable row, and maximum strength (1RM) in bench press and bench pull. Furthermore, in FEMD assessments, male canoeists achieved a greater F_m and F_{peak} than female canoeists on the canoe-specific isometric test and greater $N_{strokes}$, F_{peak}, and P_{max} in the maximal incremental tests. Similarly, centering on an international performance level, very few differences in muscle contractile properties and ROM were shown between Tier 5 and Tier 4 canoeists. Tier 5 canoeists had greater Vrd in the BF muscle of the stroke side and ES and TZ muscles of the non-stroke side. Nevertheless, significant differences were found in strength and FEMD performances. Tier 5 canoeists showed lower T_{vmax} and T_{pmax} in the Leg Press on both sides and greater $N_{strokes}$ and F_{peak} in the maximal incremental test than Tier 4 canoeists.

Muscle contractile properties assessment through TMG has been shown, among other applications, to be a useful method to characterize athletes from different sports and to try to explain sport-specific performance [9]. However, knowledge about the influence of sex or performance on muscle contractile properties has been seldom addressed in canoeing, especially in elite canoeists. Focusing on top-level kayakers, García-García et al. [19] pointed out that females only differ from males in the TZ muscle in reaction time, showing a 19.5% lower delay time from onset to 10% of Dm (this parameter has not been observed in this study). However, of the nine muscles assessed in our study with elite and world-class canoeists, differences were only found in the ST and LD muscles. Therefore, due to the few sex differences in canoeists' muscle contractile properties, it is reinforced that muscle physiological properties are common and independent of sex [31].

Centering our attention on performance differences, García-García et al. [19] also established differences between two female groups; nonetheless, these groups were not classified according to their international performance level, but rather only according to kayaking practice (top-level kayakers vs. non-kayakers). These authors obtained notable group differences in the LD and TZ muscles, although these findings are not comparable to ours due to the difference in sample characteristics. In our study, greater Vrd in the BF, TZ, and ES muscles can be seen in male medalists at a major international event (Tier 5). In this sense, it should be highlighted that establishing differences between two high-level groups that differ exclusively by winning a medal in an international event is somewhat straightforward. In fact, some of our canoeists classified as Tier 4 due to being a finalist at a major event when data were collected would currently be classified as Tier 5 for winning a medal at the end of the season after the major canoe international event. Therefore, to establish nuances between the muscular contractile properties of elite and world-class canoeists, very sensitive parameters should be used. In this sense, Vrd could be an appropriate parameter due to its sensitivity as a physiological marker of acute variations in speed and power performance of team sports athletes [32] and as a performance predictor in endurance sports such as cycling [20]. In brief, more research is needed to define the muscle contractile properties of female and male world-class canoeists due to their practical usefulness for training and talent detection.

Regarding canoeists' ROM, no significant sex differences were found in shoulder ER, IR, and AKE. These findings are similar to those reported by McKean and Burkett [33], although their sample was made up of kayakers, not canoeists. However, significant sex differences were found in YBT-UQ$_{med}$ of the stroke side, with males showing greater mobility than female canoeists. The YBT-UQ is a test that requires both shoulder stability and mobility in three different directions (medial, superolateral, and inferolateral directions). The canoe stroke technical pattern is characterized by repetitive shoulder flexion/extension movements along with large trunk rotations on the stroke side to continually attempt to increase stroke amplitude. However, canoeing is a water sport exposed to several environmental conditions (i.e., waves, water depth, upstream or downstream currents, etc.) that influence paddlers' performances and techniques in many ways [34,35]. Hence, shoulder stability is key for an effective catch and therefore the stroke. Attempting a forward catch to enhance performance requires more stability, especially of the shoulder, which may explain the high incidence of injury in this joint related to its vulnerability [36–39]. Due to the performance level of our sample, we can assume that they have undergone sport-specific adaptations caused by repeated shoulder flexion/extensions and trunk rotations. This can be seen in the significant differences in YBT-UQ in the superolateral direction of the non-stroke side, where world-class canoeists showed greater stability in the non-stroke side (arm of the upper paddle grip), which may be a consequence of seeking a forward catch of the stroke side. In addition, males showed 5.64% more mobility and stability than female canoeists in YBT-UQ in the medial direction of the stroke side. However, these sex differences may be because women canoeists have not yet reached men's level of development, mainly due to their recent incorporation into this modality.

Muscle strength and power have an important influence on flatwater paddlers, especially their upper-body muscle strength [1]. Of note, our results showed that male canoeists obtained greater performance in strength and FEMD tests than female canoeists. These findings could be explained, among other factors, by the fact that canoeists' strength production is directly conditioned by the cross-sectional area of the analyzed muscle. Therefore, it is influenced by the lower percentage of muscle mass in female canoeists [40]; that is, males' greater strength is likely not because of higher voluntary activation but rather their greater muscle mass and type II fiber areas than females [41]. In addition, there is a large sex difference in circulating testosterone concentrations, which is related to muscle mass and strength. This largely explains the sex differences in muscle mass and strength and circulating hemoglobin levels that translate into at least an 8–12% ergogenic advantage in men [42].

Specifically, male canoeists showed greater F_{max} in the Leg Press on both sides (25.98% and 28.88%) than female canoeists and a greater F_m on the non-stroke side (16.37%). This could be related to males' greater development of force transmission in the front leg than females when applying the forward force to propel. This is a very complex duty to avoid boat pitching in each stroke. Although the lower-limb strength developed in canoeists has been seldom studied, its influence on canoeists' performance should not be underestimated.

Notably, male canoeists have greater maximum force (1RM) in the bench press (37.2%) and bench pull (17.7%) than female canoeists. This seems logical since the sex differences in strength are more pronounced in upper-body muscles compared to lower-body muscles and in concentric compared to eccentric contractions [41]. Male canoeists also have greater Pm (47.9%) and Pmax (45.9%) in the canoe-position cable row (45.95%). This exercise is commonly used in canoeing as a specific strength exercise; however, we have standardized the load to half body weight to allow comparison of relative force and speed between the sexes. Similar sex differences have also been found in other upper-body row exercises (free prone bench row, bent-over barbell row, and Smith machine bent-over row), with males showing higher speeds at different relative loads compared to females [43]. Similarly, higher load–velocity profiles were identified in males compared to females, with males showing higher velocities for light loads, although females reported higher velocities for heavy loads [44].

Finally, our male canoeists also achieved greater F_m (29.4%) and F_{peak} (31.5%) than female canoeists on the specific isometric FEMD test and greater $N_{strokes}$ (38.1%), F_{peak} (36.9%), and P_{max} (37.6%) in the maximal incremental FEMD test. To our knowledge, this is the first study that assesses elite and world-class canoeists using a canoe-specific FEMD test. This technological device provides greater specificity for assessing the strength and power performance of the water phase of the stroke on dry land. Overall, male canoeists showed greater performance than females in both concentric and isometric contraction. However, it is necessary to point out that it is very likely that these differences are smoothed out when force production is calculated based on relative body weight since both men and women increase muscle size and strength after weeks of strength training but women experience greater relative improvements in strength as a function of age and muscle group [41]. Along the same lines, men and women adapt to resistance training with similar effect sizes for hypertrophy and lower-body strength, but women have a larger effect for relative upper-body strength [45]. However, it is necessary to keep in mind that the studies included in these meta-analyses are not carried out with well-trained athletes, so they should be taken with caution.

On the other hand, it is very relevant to establish performance factors that determine canoe performance; that is, factors that are sensitive enough to differentiate between two close performance levels. Our findings indicate that canoeists with a higher international performance level, that is, medalists at a major international event classified as world-class canoeists (Tier 5), showed lower T_{vmax} and T_{pmax} in the Leg Press on both sides. In other words, they reach earlier peak strength and power in their lower limbs than Tier 4 canoeists. This may be an advantage when applying force with the lower-limb action for obtaining boat propulsion in less time and reducing speed loss, which is key throughout the aerial phase of the stroke until the catch of the next stroke in a canoe. It has already been pointed out that leg action contributes to kayak propulsion through forward forces applied to the footrest, with the highest-level kayakers producing larger forces [7,15]. It should be noted that, unlike kayakers, canoeists do not apply the forward force to the footrest but rather they do it using a forward lower-limb action through posterior pelvic tilt and the kneeling knee in the catch moment. Paquette et al. [46] pointed out that canoeists' kneeling positions may require more muscle mass than seated kayakers. Therefore, it seems reasonable to speculate, in view of the findings, that lower-limb action in canoeing could also be key to propulsion in each stroke.

In addition, male canoeists with greater performance in major international events achieved higher $N_{strokes}$ (16.5%) and F_{peak} (19.8%) in the maximal incremental FEMD test, which seems logical due to its high specificity. This is no surprise because, on the one hand, the importance of training and assessing strength through specific exercises kinematically similar to stroke movement in kayakers has already been highlighted [8] so it seems reasonable that it can also be applied to canoeists, and on the other hand, Peak Force is a good indicator of on-water strength [47].

In summary, canoeists with higher performance take longer to become exhausted and consequently obtain greater peak strength. By achieving a greater number of strokes in the incremental FEMD test, they also achieve a greater peak force to overcome the incremental load. This finding is consistent with the fact that expert paddlers have a higher level of hypertrophy than less expert paddlers in areas such as the biceps, abdomen, back muscles, quadriceps, and hamstrings [1]. These muscular factors are closely related to the production of aerobic and anaerobic power [1]. In contrast, and somewhat surprisingly, no differences were obtained in the maximum isometric FEMD test.

Our findings suggest that a canoe-specific maximum incremental test assessed through FEMD could be an appropriate device to monitor and control canoeists' performance on dry land. It should be noted that higher-level paddlers should be capable of achieving good power levels during specific rowing and speed-strength exercises [1]. This type of test using FEMD fits perfectly into this performance premise. However, as mentioned above, to our knowledge, this is the first work that implements an incremental maximum effort protocol until exhaustion with an FEMD. Undoubtedly, it is necessary to continue developing effort protocols on this basis to clarify the parameters derived from this type of test that determine performance in canoeists.

The main limitation of this study is that women's canoeing development has not yet reached the men's level, and this might overestimate "natural" sex differences. Women in canoeing have evolved to the point of equality between distances and modalities, and this was inconceivable 10 years ago. In addition, with a sample of such a high international performance level, it is very difficult to establish differences between being a finalist at a major international event of the sport or winning a medal, mainly because canoeists are highly exposed to weather conditions (i.e., wind and waves direction) due to their one-side stroke. It should be noted that the canoe does not have a rudder, so canoeists steer their boat with their paddle during the stroke. The perfect conditions for all the finalists occur in very few competitions, or at a certain time of the day, which does not necessarily coincide with the canoe race during a competition. In situations of wind direction from the non-stroke side, canoeists become very vulnerable due to the great efforts invested in maneuvering actions to maintain the course. Hence, depending on the wind direction, either the right- or the left-handed canoeist may be favored. This can make a difference when it comes to winning a medal. Moreover, we characterized our sample's body composition based on a bioelectrical impedance analysis, which also limited our study. Not being able to strictly follow the recommended guidelines for bioelectrical impedance analysis due to athletic lifestyle has not guaranteed us sufficient accuracy in data prediction. Therefore, it has also limited exploring whether body composition data have an influence on the variables studied.

This study reinforces the utility of the use of technological devices, such as TMG and FEMD, for assessing and monitoring world-class athletes, and the importance of canoeists' lower-limb strength. These results allow for creating a performance profile of female and male high-level canoeists that can help coaches obtain reference data to improve their training programs and talent detection assessments in canoeing.

5. Conclusions

Canoeists' contractile properties and ROM differ little between males and females and international medalists and non-medalists; however, strength and dynamometry performance show significant sex differences. Male canoeists had greater F_{max} in the Leg Press, P_m and P_{max} in the canoe-position cable row, and a greater 1RM in the bench press and bench Pull. Furthermore, male canoeists achieved greater F_m and F_{peak} than female canoeists in the canoe-specific isometric FEMD test and greater $N_{strokes}$, F_{peak}, and P_{max} in the incremental FEMD test. International medalists in major events showed lower T_{vmax} and T_{pmax} values in the Leg Press on both sides and greater $N_{strokes}$ and F_{peak} in the maximal incremental FEMD test than finalists in major events. From a practical point of view, these results will allow us to create a performance profile for high-level canoeists. This profile will help coaches base their training programs on improving performance or even their assessments to detect talented athletes in the canoe modality, in both men and women.

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