ORIGINAL ARTICLE

Neuromuscular characteristics of elite and age groups triathletes from world multisport championships

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ABSTRACT

This study aimed to (1) characterize the contractile properties of the main muscles involved in the World Triathlon disciplines; (2) determine to what extent sex and specialization influences neuromuscular characteristics; (3) establish lateral asymmetry profile of athletes' contractile properties. 51 aquathlon, duathlon, cross and long-distance triathletes were assessed through Countermovement Jump (CMJ) and a muscle contractile properties assessment in rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) and biceps femoris (BF) using tensiomyography prior to the Multisport World Championship. Female triathletes showed a lower CMJ ability than male triathletes in all disciplines (p = .017; ηp^2 = 0.152), with no differences between disciplines. Females showed a lower contraction time (Tc) in right VM (p = .014; ηp^2 = 0.162). Small differences were found in contractile properties between disciplines. In conclusion, no significant sex o discipline differences were found in multisport athletes' contractile properties, although women exhibited significant lower jumping ability and greater asymmetry than males in the Tc of the VM. These results provide reference values for different triathlon disciplines that can be of great importance for improving performance and to prevent injuries upon knowing the sport asymmetry profile.
Keywords: Performance analysis, Sports performance, Tensiomyography, Long-distance triathlon, Cross triathlon, Duathlon, Aquathlon.

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INTRODUCTION

Multisport is used to refer to a sport that involves more than one discipline. Since 2017, World Triathlon has launched the Multisport World Championships for professional (elite) and non-professional age-groupers (AG) athletes, bringing together in one venue different discipline such as duathlon (run-bike-run), cross triathlon (swim-mountain bike-trail run), aquathlon (swim-run) and long-distance (LD) triathlon (swim-bike-run). The characteristics and distances of these events are highly variable, ranging from less than 30 minutes in aquathlon, to a minimum of 5 hours in LD triathlon (World Triathlon, 2024).

Despite the growing importance of these modalities, the profile of these athletes has barely been studied. This fact makes it difficult to establish a scientific basis on which are the most influential performance factors in each modality (Lepers and Stapley, 2010). In short distance triathlon, it has been determined that factors such as physiological, neuromuscular, biomechanical, tactical strategy or interaction between disciplines play a fundamental role in performance (Cuba-Dorado et al., 2022). Furthermore, sex-related differences in performance have been described in different modalities and performance levels such as elite and non-elite LD triathletes (Lepers, 2019, Cuba-Dorado et al., 2023), elite cross triathletes (Lepers and Stapley, 2010) or age group duathletes (Romero-Ramos, et al., 2020). However, when performance factors are addressed, women are not usually included in the sample (Lepers, 2019, Barbosa et al., 2019). This fact makes it difficult to reliably understand the physical and physiological characteristics of female triathletes to help them achieve their maximum performance (Lepers, 2019).

Among triathlon performance factors, athletes' neuromuscular profile has not been widely addressed, despite being aware that neuromuscular training adaptations are closely related to performance in any of its disciplines (Cuba-Dorado et al., 2022, Bonacci et al., 2009). Therefore, further research is needed to understand the specific adaptations in response to triathlon training (Bonacci et al., 2009). This neuromuscular profile can be approached from different perspectives: explosive strength with Squat Jump, explosive elastic strength with Countermovement Jump (CMJ) and reflex-elastic-explosive strength assessments with Drop Jump (Loturco et al., 2015, Mueller et al., 2015, Suzuki et al., 2006); muscle electrical activity assessment through Electromyography (Brisswalter et al., 2014, Jacques et al., 2021) or superficial muscle contractile properties assessment using Tensiomyography (TMG).

Tensiomyography assesses muscle contractile properties through the radial deformation of the muscular belly produced by a single electrical stimulus. This is a non-invasive method that does not require physical effort for the athlete. Few studies have characterized well-trained athletes from different triathlon disciplines through TMG, so greater knowledge is essential to effectively interpret the parameters obtained (García-García et al., 2019). Regarding multisport athletes, to our knowledge, it has been used to assess muscle fatigue in non-elite duathletes (Rojas-Valverde et al., 2021) and LD triathletes (Cuba-Dorado et al., 2023, García-Manso et al., 2011). In addition, TMG has also been used to assess lateral asymmetry proven to be an excellent reproducibility tool (Iglesias-Caamaño et al., 2018).

The relationship between lower-limb asymmetries and athletic performance in endurance athletes is complex and multifactorial. Some studies suggest that these asymmetries may negatively impact performance, while others indicate that certain inequalities may not be decisive. In endurance athletes, D´Hondt et al. (2024) reported a negative or non-significant relationship with running performance in most of the asymmetry indicators addressed in their systematic review, except of ankle dorsiflexion, where a more marked effect was observed.

On the other hand, regarding the relationship between lower-limb asymmetries and injury, the scientific evidence remains ambiguous since not all functional tests have the same predictive capacity (Guan et al., 2022). However, there is consensus that differences greater than 10-15% between limbs increase the risk of injury (Impellizzeri et al., 2007, Hamilton et al., 2008). Nevertheless, in response to the subjectivity of these "*arbitrary*" thresholds, the "*specific*" thresholds have emerged (Dos´Santos et al., 2021). These new thresholds seek to establish a consensus on the magnitude of asymmetry, favouring each specific sample to apply its specific magnitude of asymmetry. This allows coaches to use these thresholds as reference, criterion, and normative data for specific populations.

Considering the scarce scientific evidence regarding neuromuscular properties of multisport athletes, this study aims to characterize the contractile properties of the main muscles involved in the Multisport World Triathlon disciplines, and to determine to what extent sex and specialization influences neuromuscular characteristics. In addition, establishing lateral asymmetry profile of athletes' contractile properties.

MATERIAL AND METHODS

Study design

A transversal cross-sectional study design, following an associative strategy was used to assess triathletes' neuromuscular properties. Triathletes were assessed within 48 h prior to the Multisport World Championship to establish neuromuscular basal values. The testing protocol was carried out in the following order: body composition analysis, TMG and Countermovement Jump. To establish neuromuscular data reliability, six randomly chosen triathletes were evaluated twice.

Participants

Forty-four elite and well-trained AG athletes, who competed in the aquathlon, duathlon, cross-triathlon and LD triathlon 2019 Multisport World Championship composed our sample (Table 1). Following McKay et al's (2022) classification based on training volume and performance metrics, our athletes belong to Tiers 3 (Highly Trained/National Level), 4 (Elite/International Level) and 5 (World Class). Written informed consent was obtained from all the athletes included in the study. The research protocol followed the principles of the Declaration of Helsinki regarding biomedical research involving human subjects (64th World Medical Assembly 2013) and had the World Triathlon and the University of Vigo Ethics Committees approval.

Procedure

Countermovement Jump (CMJ)

Countermovement Jump was conducted using the Chronojump BoscoSystem contact platform (Chronojump BoscoSystem®, Barcelona, Spain) instructing the athletes to jump as high as possible while keeping their hands on the hips (Gathercole et al., 2015). Height was calculated by recording flight time through the CHRONOJUMP software (v. 1.7.0 for Windows, Chronojump BoscoSystem®, Barcelona, Spain). This jumping test was selected due to its short-duration and the low-fatigue that could produce competition performance. Moreover, CMJ has been previously related to running economy (Hunter et al., 2015, Paavolainen, 1999, Ramírez-Campillo, 2014), being the run segment part of all the multisport disciplines.

Contractile properties assessment

Vastus Lateralis (VL) and Medialis (VM), Rectus Femoris (RF) and the long head of the Biceps Femoris (BF) from both legs were assessed through TMG following García-García et al.'s (2019) protocol. These four muscles were selected based on their influence in all three triathlon segments (swim, bike, run) and impact on the final outcome. Triathletes were assessed lying on a stretcher following Perotto's et al. (2005)

anatomical guidelines for sensor placement (GK 30, Panoptik d.o.o., Ljubljana, Slovenia). Two self-adhesive electrodes (5 x 5 cm, Lessa®, AB Medica Group SA, Spain) were placed symmetrically at 5-cm from the digital transducer that applied the progressive electric stimulation in 10-mA steps until reaching the maximal stimulator output (110-mA) (EMF-FURLAN & Co. d.o.o., Ljubljana, Slovenia). The curve with the highest maximum radial displacement for each muscle was included in for analysis. All measurements were carried out by two expert TMG evaluators. The following parameters were recorded: 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 by the rate ($mm \cdot s^{-1}$) between the radial displacement occurring during the period of Tc (Vrd = (0.8 × Dm)/Tc × 1000).

Analysis

Countermovement Jump and tensiomyography absolute and relative intrarater reliability was calculated through intraclass correlation coefficient (ICC), ICC based on 95% confident interval (IC95%) and coefficient of variation (CV), carrying out a two-way mixed effects model. Sex and specialization (discipline) influence on TMG parameter was assessed with a two-factor ANOVA verifying previously sample's normal and linear distribution through the univariate Kolmogorov-Smirnov test, in conjunction with the Lilliefors test. Homoscedastic assumption was verified with the Box M test followed by a post-hoc HSD Turkey test. Effect sizes in two-way ANOVA were reported as partial eta square (ηp^2) and interpreted as small (0.01), moderate (0.06), or large (0.14). Statistical significance level was set at <.05 alpha. All data were analysed using SPSS v.24.0 for Windows (SPSS Inc., Chicago, IL, USA).

To classify triathletes as "*asymmetrical*", the specific asymmetry thresholds procedure of Dos'Santos et al. (2021) was followed: %Asymmetry + (0.2 × SD). The % of Asymmetry and SD are the average percentage and standard deviation of the sample's asymmetry. This classification was applied individually to each variable of TMG.

RESULTS

The reliability values were ICC = 0.96, IC95% = (0.93-0.99) and CV = 3.1% for Dm; ICC = 0.95, IC95% = (0.90-0.98) and CV = 2.6% for Tc, and ICC = 0.93, IC95% = (0.86-0.96) and CV = 6.1% for CMJ.

The results indicate that female triathletes have much less countermovement jumping ability than male triathletes in all analysed disciplines (p = .017; ηp^2 = 0.152). However, there are no differences between disciplines (21.19 vs 22.47 vs 21.73 vs 20.90 cm; p = .835; ηp^2 = 0.024).

Regarding Tc parameter, there are no differences between female and male triathletes (see Table 2), except for the right VM, where female triathletes showed a lower Tc in all assessed muscles (p = .014; ηp^2 = 0.162) with a large effect size. Regarding differences between disciplines, no differences were found, except cross triathletes that showed a higher Tc in the left BF than standard duathlon triathletes (43.99 ± 3.8 vs 30.71 ± 4.40 ms; p = 0.03) and LD triathletes (43.99 ± 3.8 vs 34.19 ± 2.81 ms; p = .04) both with a large effect size (ηp^2 = 0.149).

Concerning Dm, there are no differences between female and male triathletes, neither in BF nor VM between disciplines. Only the Dm of the right RF from cross triathlon athletes is lower than aquathlon triathletes with a large effect size (7.97 ± 0.92 vs 11.01 ± 0.88 mm; p = .017; ηp^2 = 0.149) and the right Dm of the VL from standard duathlon athletes is lower than that of LD triathletes with a large effect size (4.50 ± 0.65 vs 6.62 ± 0.38 mm; p = .008; ηp^2 = 0.187).

Table 1. Athletes' characteristics based on the Multisport World Championship disciplines (mean ± SD).

Discipline (distance km)		n	Age	Height*	Body Composition†			Competition Time	Weekly Training
		Total (elite)	**(years)**	**(cm)**	**Body Mass (kg)**	**Fat (%)**	**Muscle mass (kg)**	**(min)**	**(h)**
Standard duathlon (10-40-5)	Female	2 (1)	33.50 ± 16.26	166.00 ± 0.71	54.05 ± 0.92	16.25 ± 1.63	42.95 ± 1.49	140.52 ± 23.97	16.50 ± 12.02
	Male	4	38.75 ± 8.77	173.50 ± 5.02	71.05 ± 7.34	10.75 ± 6.40	59.93 ± 1.92	138.75 ± 16.39	18.25 ± 11.35
	Total	6 (1)	37.00 ± 10.32	171.00 ± 5.50	65.38 ± 10.47	12.58 ± 5.76	54.26 ± 8.92	140.05 ± 16.80	16.20 ± 10.85
Cross triathlon (1-30-7)	Female	3 (3)	25.67 ± 9.87	156.90 ± 3.26	51.33 ± 2.67	15.50 ± 2.95	41.23 ± 3.51	143.63 ± 4.23	19.00 ± 4.00
	Male	4 (3)	27.00 ± 7.52	180.70 ± 6.68	69.28 ± 7.80	7.28 ± 2.62	61.15 ± 8.32	124.17 ± 12.59	18.50 ± 4.44
	Total	7 (6)	26.43 ± 7.83	170.50 ± 13.70	61.59 ± 11.17	10.80 ± 5.06	52.61 ± 12.33	132.51 ± 13.91	18.71 ± 3.90
Aquathlon (1-5)	Female	3 (3)	20.33 ± 0.58	165.93 ± 8.50	59.00 ± 5.20	17.53 ± 3.75	46.23 ± 5.38	35.54 ± 1.59	26.50 ± 7.78
	Male	5 (2)	31.40 ± 7.86	179.32 ± 1.17	75.62 ± 8.98	10.40 ± 5.12	64.18 ± 6.11	37.12 ± 11.33	19.40 ± 3.78
	Total	8 (5)	27.25 ± 8.26	174.30 ± 8.33	69.39 ± 11.30	13.08 ± 5.71	57.45 ± 10.26	36. 44 ± 8.11	21.43 ± 5.62
Long distance (1.5‡-113-30)	female	5 (2)	36.80 ± 9.47	165.42 ± 6.13	57.44 ± 5.25	16.52 ± 4.91	45.38 ± 3.36	466.64 ± 83.73	19.80 ± 8.17
	Male	18 (2)	36.17 ± 8.12	176.48 ± 5.43	71.74 ± 6.96	10.21 ± 3.89	61.08 ± 5.20	418.77 ± 46.84	15.94 ± 4.34
	Total	23 (4)	36.30 ± 8.28	174.07 ± 7.17	68.63 ± 8.88	11.57 ± 4.81	57.67 ± 8.17	429.65 ± 58.56	16.82 ± 5.46
Total	Female	13 (9)	29.92 ± 10.84	163.66 ± 6.43	55.87 ± 4.91	16.48 ± 3.55	44.25 ± 3.86	242.44 ± 195.47	19.73 ± 7.68
	Male	31 (7)	34.55 ± 8.54	177.10 ± 5.33	71.96 ± 7.28	9.93 ± 4.24	61.44 ± 5.40	286.87 ± 166.44	17.17 ± 5.47
	Total	44 (16)	33.18 ± 9.40	173.13 ± 8.35	67.21 ± 9.94	11.86 ± 5.02	56.36 ± 9.35	273.12 ± 174.74	17.85 ± 6.14

*Note. *Height was measured through a stadiometer (Seca 213, Seca gmbh & co. kg., Hamburg, Germany). †Body composition was analysed through a Bioelectrical Impedance Analysis (Tanita MC-780MA, Tanita Corporation, Tokyo, Japan). ‡ The original 3-km swim segment was shortened following World Triathlon regulations due to low water and air temperature.*

Table 2. Descriptive statistics of neuromuscular variables based on sex and discipline.

Parameter	Standard duathlon		Cross triathlon		Aquathlon		LD triathlon	
	Female	Male	Female	Male	Female	Male	Female	Male
CMJ	20.63 ± 0.65	21.76 ± 3.62	20.49 ± 2.02	24.45 ± 3.20	20.09 ± 3.14	23.37 ± 6.26	17.97 ± 3	23.82 ± 3.96
Tc BF right	32.13 ± 0.24	31.56 ± 4.3	44.27 ± 14.6	34.77 ± 6.63	39.04 ± 10.3	34.18 ± 8.98	31.09 ± 3.45	39.07 ± 13.8
Tc BF left	28.34 ± 0.5	33.08 ± 8.59	44.44 ± 18.09	43.55 ± 15.7	35.10 ± 7.57	35.64 ± 5.43	31.77 ± 2.33	36.61 ± 10.1
Tc RF right	29.88 ± 0.02	30.88 ± 10.7	23.16 ± 2.08	30.34 ± 4.67	25.05 ± 0.90	29.44 ± 3.06	26.59 ± 1.08	29.21 ± 5.56
Tc RF left	29.87 ± 3.25	27.77 ± 4.14	25.15 ± 1.69	28.14 ± 5.95	28.54 ± 3.27	28.55 ± 3.95	25.57 ± 4.27	29.07 ± 4.72
Tc VL right	22.91 ± 0.00	22.89 ± 2.44	24.15 ± 3.77	25.41 ± 4.96	20.55 ± 1.99	25.66 ± 2.29	22.81 ± 1.84	24.43 ± 3.63
Tc VL left	22.26 ± 0.13	23.14 ± 2.31	23.00 ± 1.38	24.82 ± 4.36	22.99 ± 2.42	24.44 ± 0.77	20.99 ± 1.18	24.86 ± 3.77
Tc VM right	22.11 ± 0.36	23.68 ± 1.94	23.07 ± 2.05	23.80 ± 3.62	19.55 ± 1.22	23.53 ± 1.07	21.54 ± 0.84	23.43 ± 2.30
Tc VM left	25.08 ± 4.12	25.18 ± 1.40	24.13 ± 1.41	23.39 ± 3.82	23.55 ± 1.73	23.22 ± 1.25	21.27 ± 1.58	23.34 ± 2.03
Dm BF right	7.72 ± 0.43	6.86 ± 2.33	10.73 ± 1.66	7.17 ± 0.86	7.09 ± 1.65	9.03 ± 2.89	8.52 ± 3.25	8.09 ± 1.87
Dm BF left	7.85 ± 1.15	7.64 ± 2.61	8.80 ± 1.71	7.79 ± 1.07	7.68 ± 0.38	8.76 ± 3.55	7.61 ± 3.29	8.12 ± 1.69
Dm RF right	9.78 ± 1.19	8.51 ± 4.77	6.76 ± 2.46	9.17 ± 2.50	10.84 ± 2.88	11.18 ± 1.46	9.24 ± 1.05	8.74 ± 2.08
Dm RF left	7.64 ± 0.57	8.60 ± 4.42	6.79 ± 0.57	9.08 ± 1.76	8.45 ± 2.84	8.77 ± 2.09	8.36 ± 1.65	8.68 ± 2.31
Dm VL right	4.05 ± 0.34	4.95 ± 1.32	5.52 ± 1.42	6.98 ± 1.95	5.33 ± 1.15	6.13 ± 1.12	6.95 ± 0.5	6.29 ± 1.76
Dm VL left	4.62 ± 1.44	5.18 ± 1.51	5.89 ± 1.63	7.44 ± 2.15	6.20 ± 0.90	6.22 ± 2.23	6.61 ± 1.11	6.42 ± 1.52
Dm VM right	7.82 ± 1.40	7.15 ± 1.08	7.09 ± 0.61	8.20 ± 0.97	6.86 ± 1.22	8.33 ± 1.93	7.27 ± 2.15	8.46 ± 1.32
Dm VM left	6.51 ± 1.22	7.23 ± 1.34	7.80 ± 1.58	8.81 ± 1.30	8.60 ± 2.16	7.89 ± 2.19	6.99 ± 1.53	8.23 ± 1.78
Vrd BF right	192.2 ± 12.3	171.9 ± 46.1	203.2 ± 47.4	167.6 ± 23.4	149.3 ± 32.6	208.9 ± 19.2	216.1 ± 67.7	175.9 ± 47.8
Vrd BF left	221.3 ± 28.8	181.9 ± 23.2	170.2 ± 44.2	153.3 ± 39.9	180.1 ± 34.9	191.0 ± 64.9	188.0 ± 66.9	184.0 ± 43.6
Vrd RF right	261.9 ± 31.7	211.7 ± 87.1	231.2 ± 69.3	238.1 ± 32.6	348.8 ± 103.7	304.8 ± 35.3	278.5 ± 72.7	241.9 ± 53.0
Vrd RF left	206.6 ± 38.0	240.7 ± 101.1	216.4 ± 17.3	259.6 ± 18.4	243.2 ± 104.6	244.2 ± 46.0	265.9 ± 66.8	240.9 ± 61.4
Vrd VL right	141.5 ± 12.1	172.2 ± 37.2	183.8 ± 44.6	220.5 ± 49.3	207.1 ± 38.2	193.5 ± 45.4	246.1 ± 37.4	207.3 ± 52.7
Vrd VL left	166.3 ± 53.0	177.6 ± 36.6	203.5 ± 46.2	235.8 ± 32.7	215.2 ± 13.7	204.0 ± 73.8	252.1 ± 40.4	208.3 ± 46.0
Vrd VM right	282.3 ± 45.9	241.9 ± 34.1	246.3 ± 16.1	282.2 ± 61.8	280.5 ± 41.8	284.2 ± 68.0	268.0 ± 72.0	290.7 ± 50.3
Vrd VM left	207.3 ± 4.9	228.9 ± 34.1	261.1 ± 68.4	305.5 ± 48.7	292.6 ± 72.6	271.8 ± 75.3	266.9 ± 78.3	284.6 ± 70.4

Note. LD (long distance); CMJ (height of countermovement jump, in cm); Tc (contraction time, in ms); BF (biceps femoris); RF (rectus femoris); VL (vastus lateralis); VM (vastus medialis); Dm (maximum radial muscle belly displacement, in mm); Vrd (radial displacement velocity, in mm·s^{-1}*).*

In relation to Vrd, there are no differences between female and male triathletes either (see Table 2). Neither BF nor VM show differences between disciplines. On the contrary, the right RF of aquathlon triathletes is much faster (321.37 ± 65.64 mm·s-^{1}) than that of duathlon triathletes (228.45 ± 73.73 mm·s -^{1}) and LD triathletes (248.60 ± 51.80 mm·s-^{1}) with a large effect size ($\eta p^2 = 0.255$). In addition, both VLs are slower in standard duathlon athletes than in LD triathletes with a large effect size (right 156.84 ± 20.37 vs 226.78 ± 11.89 mm·s-^{1}; *p* = .005; $\eta p^2 = 0.200$; left 171.98 ± 20.37 vs 230.22 ± 13.00 mm·s-^{1}; *p* = .021; $\eta p^2 = 0.146$).

No differences were observed in the magnitude of lateral asymmetries of BF, RF and VL between male and female triathletes, or between disciplines. On the contrary, female triathletes have a greater asymmetry than male triathletes in the Tc of the VM (9.89 vs 5.26%; *p* = .006) with a large effect size ($\eta p^2 = 0.197$). In addition, Tc asymmetry of the VM is lower in cross triathletes (3.18%) than Duathlon triathletes (9.20%, *p* = .039) and aquathlon triathletes (10.64%, *p* = .006) with a large effect size ($\eta p^2 = 0.213$).

In relation to lateral asymmetry direction of the VM, both men and women was towards non-dominant limb, being this limb the one with the highest Tc and the dominant limb the one with the lowest Tc in VM. Likewise, the asymmetry of the Tc of the VM in cross, duathlon and aquathlon triathletes was towards non-dominant limb.

Specific asymmetry thresholds categorize triathletes as "*asymmetrical*" when their lateral asymmetry in muscle contractile properties of BF was greater than 33.6% in Dm, 25.6% in Tc and 49.5% in Vrd. Only 5.9%, 5.9% and 3.9% (respectively) of the triathletes were categorized asymmetrical. Triathletes were classified as asymmetrical in RF when lateral asymmetry exceeded 14.1% for Tc, 39.5% in Dm and 38.9% in Vrd. A 21.6 % for Tc, 3.9 for Dm and 3.9% for Vrd of the triathletes were asymmetrical. Triathletes were classified as asymmetrical in VL when lateral asymmetry exceeded 6.5% for Tc, 34.6% in Dm and 30.2% in Vrd. A 39.2% for Tc, 3.9% for Dm and 11.8% for Vrd of the triathletes were asymmetrical. Finally, triathletes were classified as asymmetrical in VM when lateral asymmetry exceeded 8.1 % for Tc, 30.1 % in Dm and 27.6 % in Vrd. A 33.3 % for Tc, 9.8 for Dm and 9.8 % for Vrd of the triathletes were asymmetrical.

DISCUSSION

The main findings of this study indicate that female triathletes have much lower CMJ ability than male triathletes in all the analysed disciplines. However, few significant sex-differences were found between female and male contractile properties, and World Triathlon disciplines.

Our sex-differences in CMJ performance are in line with previous reference power values for jump squat for endurance athletes (long distance runners and triathletes), showing considerably lower values for females than males (Valenzuela et al., 2020).

Regarding contractile properties, very few sex-differences were obtained between triathletes. Females' Tc of the left VM was lower than males in all World Triathlon disciplines, with female triathletes also showing greater lateral asymmetry than males in Tc of the VM. The meagre sex-differences found in contractile properties does not resemble with the performance differences reported by other authors (Lepers, 2019, Lepers and Stapley, 2010, Barbosa et al., 2019), therefore sex-differences in performance are explained by other factors. Lepers and Stapley (2010) have pointed out sex-differences in cross triathlon performance, especially in the cycling segment, suggesting that cycling technical characteristics can have a direct influence in type of races, encouraging the exploration of physiological factors that may influence performance. However, contractile properties do not seem to be one of them. Neither seem to have any influence in LD triathlon where the technical component is lower and where sex-differences, despite having been considerably reduced over the years, are still present (Lepers, 2019). These findings are similar to those found in other sports such as canoeing, where barely sex-differences in muscle contractile properties were reported (Álvarez-Yates et al., 2024a). This reinforces the idea that muscular physiological properties are common and independent of sex (Staron et al., 1994).

Concerning the analysis between World Triathlon disciplines, no differences were found in the CMJ between disciplines, however few differences were shown in contractile properties. This may be because Olympic-distance triathletes often race in other disciplines over the season. The main contractile properties differences were found in cross triathletes, showing a higher Tc in the left BF than duathletes and LD triathletes, and a lower Dm in the right RF than aquathlon athletes. These results are in line with García-Manso et al. (2011) that found Tc values in the left BF greater than the double of the right BF in LD triathletes, however in our results LD triathletes do not show such difference. In addition, our duathlon athletes exhibited a lower Dm in the right VL and a lower Vrd in both right and left VL than LD triathletes, while aquathlon athletes showed a higher Vrd in the right RF than duathletes and LD triathletes. Nevertheless, it should be noted that the Dm of the RF of aquathlon athletes, of both female and male, turned to be greater than the other analysed disciplines. If we compare these values with well-trained cyclists (García-García et al., 2013, 2018), aquathlon athletes' Dm values in RF are still much higher than cyclists. Therefore, it would be interesting to analyse whether not performing the cycling segment in these athletes can influence a lower muscle tone in this musculature. Finally, the lateral asymmetry of the Tc in VM was lower in cross triathletes than duathlon and aquathlon athletes.

To our knowledge, this is the first study that attempts to characterize the different triathlon modalities at the neuromuscular level. When comparing contractile properties values with athletes from similar movement patterns to triathlon, it can be noted that our triathletes' average Tc value from the VM and RF are lower than cyclist values reported by García-García et al. (2013, 2018), both during preparatory and competition period. Similarly, the average Tc value from the VL in all analysed disciplines is slightly lower than mountain marathon runners reported by Giovanelli et al. (2016). Regarding the Tc values of BF from our results, these are similar to cyclists (García-García et al., 2013, 2018) except for the left leg of cross triathletes' which showed greater values. However, if we compare our results with those obtained with LD triathletes by García-Manso et al. (2011) we can observe that all average values are lower than their average left BF, and higher than the right BF.

Furthermore, high intensity training decreases muscle contraction time (Tc), specifically in those involved in training (Šimunič, 2011). Therefore, athletes from sports that require greater strength and power, are usually characterized by lower Tc than endurance athletes (García-García et al., 2019). Accordingly, it is not unreasonable to think that specialized athletes in different triathlon modalities may present higher Tc values than athletes than require speed strength due to their sports characteristics. Comparing our data with other sports, it is noted that our male knee extensor muscles values (RF, VL and VM) are within males' soccer players values (García-García et al., 2019) and similar to male acrobatic gymnastics (Vernetta-Santana et al., 2018), and beach volleyball players (Rodríguez-Ruíz et al., 2012), the latter showing higher values in VM. Greater values are also found in the Tc of RF in tennis players (Wiewelhove et al., 2017) and tumbling gymnasts (Rojas-Barrionuevo et al., 2016) however showing the latter lower values in VL and VM. Regarding women knee extensor muscles values, duathlon athletes' VL, VM and RF values are similar to female rugby players (Valenzuela et al., 2018), although our RF values from other World Triathlon disciplines are slightly lower, as well as female beach volleyball players (Rodríguez-Ruíz et al., 2012). When comparing our data with female soccer players, their Tc values of RF are lower than all World Triathlon disciplines, except for duathlon athletes (Paravlic et al., 2022). Nevertheless, when comparing BF, female LD triathletes show higher Tc than female soccer players (Paravlic et al., 2022), while cross triathletes and aquathlon athletes showed higher Tc than beach volleyball players (Rodríguez-Ruíz et al., 2012). Male LD triathletes also showed higher values male soccer players (Fernández-Baeza, 2025) and beach volleyball players (Rodríguez-Ruíz et al., 2012). Although, when compared with acrobatic gymnasts, data differs considerably depending on the discipline (Vernetta-Santana et al., 2018). In brief, female and male triathletes, exhibit slower Tc value from the BF than other acyclic sports athletes, although showing similar quadriceps muscles values (RF, VL and VM). Even though these sports are performed at very different intensities, the high correlation between Tc and the percentage of type I fibres (Dahmane et al., 2001) together with the maximum TMG output stimulation (110 mA), could be a limitation for stimulating large motor neurons, which are more characteristic in high-intensity sports (García-García et al., 2019).

Regarding radial muscle belly displacement (Dm), our BF values, from all Word Triathlon disciplines, are higher than LD triathletes reported by García-Manso et al. (2011) and cyclists analysed by García-García et al. (2013). However, these are similar to García-García et al.'s (2018) cyclists, except for female cross triathletes and male aquathlon athletes that are higher. Male cross triathlon exhibited higher Dm in RF, VL and VM than cyclists (García-García et al., 2013, 2018), and in VL than mountain runners (2016). Female LD triathletes showed greater Dm values in left RF than cyclists (García-García et al., 2013, 2018) and left VL than cyclists (García-García et al., 2013, 2018) and mountain runners (Giovanelli et al. 2016), and a lower Dm in left VM than cyclists (García-García et al., 2013, 2018). Duathlon athletes also showed a lower Dm in VL than cyclists in both legs and a higher Dm in right RF. Moreover, regarding Aquathlon, besides the RF differences with cyclists, women also showed higher Dm values in VM than male cyclists. The remaining Dm values are in the same range as cyclists, mountain runners and long-distance triathletes.

Low values in Dm have been associated with greater muscle-tendon stiffness (Pišot, 2008), therefore, athletes who require speed strength usually present lower values in this parameter (García-García et al., 2019). Female triathletes show greater Dm in BF than beach volleyball players (Rodríguez-Ruíz et al., 2012), although there is no clear pattern in relation to knee extensors Dm when comparing with rugby players (Valenzuela et al., 2018), beach volleyball players (Rodríguez-Ruíz et al., 2012) or soccer players (Paravlic et al., 2022). Respecting males, our triathletes' Dm was higher in all analysed muscles than bodyboarders (Rodríguez-Matoso, et al. 2015), while the knee extensors showed lower or similar values to tumbling (Rojas-Barrionuevo et al., 2016), tennis (Wiewelhove et al., 2017), acrobatic gymnastics (Vernetta-Santana et al., 2018) or beach volleyball athletes, except for the VL (Rodríguez-Ruíz et al., 2012). Regarding males' BF, higher Dm values were obtained from our triathletes than soccer player (Fernández-Baeza, 2025), volleyball players (Rodríguez-Ruíz et al., 2012) and abovementioned bodyboarders (Rodríguez-Matoso, et al. 2015); although lower than acrobatic gymnasts (Vernetta-Santana et al., 2018). Therefore, Dm behaviour seems to be related to Tc when comparing sports, since quadriceps muscles (RF, VL and VM), both male and female triathletes, exhibit similar, or even lower, values than to other acyclic sports athletes. However, triathletes' BF seems to show a lower muscle tone than other sports, except gymnastics.

Concerning to lateral asymmetry, the main distinguishing characteristic observed was in Tc of VM, showing females greater asymmetry than males. These values seem to indicate that the non-dominant leg may be the limb with the highest Tc, since the stronger leg would be determined as dominant due to its greater running impulse in endurance athletes. However, this suggests the need to investigate whether the sports movements biomechanics involved in this activity can explain this.

On the other hand, no major asymmetries were found after applying Dos'Santos et al. (2021) "*specific*" thresholds. The percentage of asymmetrical athletes for the Tc of RF, VL, and VM, was 21.6 %, 39.2 % and 33.3%, respectively. Regarding the remaining parameters, only the Vrd of VL stands out, with 11.8 % of asymmetrical classified athletes, while the remaining parameters were lower than 9.8%. When comparing the "*specific*" threshold with canoeists (Álvarez-Yates et al., 2024b), both females and male, RF and BF thresholds are higher, excepting the Tc of BF (25.53%). Similarly, the percentage of asymmetrical athletes in volleyball players was higher for the Dm of BF (30.44%) and slightly lower for Dm of RF (30.12%) (Iglesias-Caamaño et al., 2022).

Overall, the results obtained in this study can help athletes from different triathlon disciplines to determine whether their neuromuscular properties meet the reference values for their discipline. This is of great importance to enhance performance through training and to prevent injuries upon knowing the sport asymmetry profile. In this sense, future lines of research should relate asymmetry thresholds to competitive performance to determine whether triathletes with the highest performance present an asymmetric profile, as occurs in other sports. Likewise, it may be of great interest to understand whether the detected asymmetries are related to injuries risk. In any case, the main limitation of this study is the small sample size of each triathlon discipline, so the results should be viewed with caution. However, to our knowledge, this is the first study to establish reference values for triathletes using a sample of high-performance athletes.

CONCLUSIONS

In conclusion, there are no significant sex o discipline differences in multisport athletes' contractile properties, although women exhibited a significant lower jumping ability than men, with no significant differences between Word Triathlon disciplines. Furthermore, there are no substantial differences in knee extensor muscles properties (Tc and Dm) between triathlon disciplines, however, triathletes exhibiting slower contraction time in BF than other sports. Finally, no sex or discipline differences were observed in the magnitude of lateral asymmetries of BF, RF and VL, only showing females a significant greater asymmetry than males in the Tc of the VM.

AUTHOR CONTRIBUTIONS

Alba Cuba-Dorado: conceptualization, methodology, software, investigation, resources, data curation, writing, review, and project administration. Tania Alvarez-Yates: methodology, investigation, writing, and review. Mario Iglesias-Caamaño: formal analysis, investigation, and writing. Javier Carballo-Lopez: software, and investigation. José Manuel Abalo-Rey: investigation. Alicia Riveiro-Bozada: investigation. Tania García-Remeseiro: investigation, and resources. Oscar García-García: conceptualization, methodology, formal analysis, investigation, resources, writing, review, and project administration. All authors have approved the manuscript and agree with its submission to JHSE.

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No potential conflict of interest was reported by the authors.

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