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NO DIFFERENCES BETWEEN MALES AND FEMALES IN THE NEURAL CONTROL OF EXPLOSIVE CONTRACTIONS

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Males and females exhibit comparable explosive relative to maximal strength. Given the greater proportion of type I fibres area in female muscles, motor units discharge rate (MUDR) in explosive efforts may be higher to compensate for slower contractile properties. To verify this, 22 females and 12 males (20-34 y), performed 10 rapid isometric ankle dorsiflexors, while recording high-density electromyography from tibialis anterior. Relative rate of torque development (RTD) measures (normalised to maximal torque) in the first 150 ms from contraction onset were not different ($P > 0.07$) between sexes, nor MUDR at the beginning of the explosive efforts (61 ± 15 vs. 67 ± 16 Hz; $P = 0.23$). Time to peak RTD was shorter in males (61 ± 12 vs. 74 ± 14 ms; $P < 0.01$). Thus, despite faster torque kinetics in males, the control of rapid torque production does not differ between sexes.

KEYWORDS: ballistic, explosive, sex differences, motor units.

INTRODUCTION: Explosive strength is the fundamental neuromuscular skill of producing the highest amount of torque in the minimum time (Ruggiero & Gruber, 2024), key for functional sports outcomes (Buckthorpe & Roi, 2018). It is quantified as the rate of torque development (RTD) of a muscle group during a maximal voluntary effort (Maffiuletti et al., 2016).
Females and males present significant differences in fundamental neuromuscular capabilities (Hunter & Senefeld, 2024). Males have greater levels of maximal strength and power, driven primarily by greater cross-sectional area, particularly of type II fibres (Hunter & Senefeld, 2024; Nuzzo, 2024). Females instead outperform males in neuromuscular fatigability when exercising at the same intensity relative to the maximal voluntary contraction torque (MVT) or power output (Hunter & Senefeld, 2024). One potential difference is the neural control of muscle force or joint torque between sexes. Several studies have focused on motor units discharge rate (MUDR) in maximal and submaximal isometric contractions. Typically, females exhibit higher MUDR than males in submaximal isometric contractions at the same relative intensity, but lower MUDR in maximal efforts (Lulic-Kuryllo & Inglis, 2022).
Given the importance of explosive strength for sports, previous studies have examined sex differences in rapid force production (e.g., Hannah et al., 2015; Inglis et al., 2017). The consensus is that when MVT is accounted for, RTD in explosive efforts is not different between males and females (Hannah et al., 2015; Inglis et al., 2017). Despite the importance of motor units discharge rate for explosive performance (Del Vecchio, 2023) no studies have determined whether sex differences in MUDR exist. Given the greater proportion of type I fibres area in female muscles (Nuzzo, 2024), with slower contractile kinetics, MUDR in explosive efforts may be higher to compensate for slower contractile properties.
The present research aimed to study sex differences in rapid torque production of voluntary explosive contractions of the ankle dorsiflexors. The firing behaviour of individual motor units was assessed via decomposition of high-density electromyography (EMG) signals recorded from the tibialis anterior muscle. We hypothesised comparable measures of relative RTD between sexes (i.e., when accounted for MVT), with higher values of MUDR in females.

METHODS: Twenty-four females (mean ± standard deviation; 27 ± 6 years; 170 ± 4 cm; 61 ± 6 kg) and 12 males (26 ± 4 years; 181 ± 7 cm; 85 ± 15 kg) participated in the study after providing informed written consent. The number of females was purposely twice that of males to account for the nearly half yield of motor units number typically found with high-density EMG. All testing procedures were approved by the Ethics Commission of the University of Konstanz (Institutional Review Board Statement 10/2023). Participants were tested on two occasions. Session 1 regarded familiarisation with isometric maximal and explosive contractions. Session 2 regarded actual measurements.

Participants sat on an isokinetic dynamometer (Isomed 2000; Ferstl GmbH, Hemau, Germany). The right foot was placed on a custom-made footplate at 30° plantarflexion and secured with Velcro straps across the instep and toes. A 90° angle at knee joint was ensured, with the thigh strapped to a C-clamp to avoid thigh movements during contractions. Ankle dorsiflexion torque was measured by a torque transducer (DV-14, Lorenz Messtechnik GmbH, Alfdorf, Germany) connected to the custom-made footplate. The output signal was amplified (x1000, LCV/U10, Lorenz Messtechnik GmbH), fed to a 16-bit multichannel device (Sessantaquattro+, OT Bioelettronica, Turin, Italy), and sampled at 2000 Hz for synchronisation with high-density EMG recordings using OT Biolab Software (OT Bioelettronica). In session 2, high-density EMG signals were recorded from the tibialis anterior muscle by means of an adhesive grid of 64 electrodes (HD08MM1305, OT Bioelettronica). This muscle group was selected due to the ease of motor unit identification in both sexes. Data collection began with the determination of isometric ankle dorsiflexion MVT by performing two brief maximal contractions (90 s rest in-between). Participants then performed two sets (2 min rest in-between) of five rapid contractions, interspersed by 1-min rest, with instructions to reach 75% MVT as fast as possible and hold it for ~3 s (Del Vecchio et al., 2019).

All signals were analysed off-line using custom MATLAB scripts. The onset of torque was identified using previously established procedures (Tillin et al., 2010). For all contractions, pRTD (10-ms moving window), time to peak RTD, and RTD in the windows 0-50, 0-100 and 0-150 ms from torque onset were derived.

High-density EMG signals were decomposed, and values of MUDR were identified following standard procedures (Del Vecchio et al., 2019).

Statistical analysis was conducted using MATLAB. All measures were compared between sexes using linear mixed-effects models (*fitlme* function; Dependent variable ~ 1 + Sex · MVT). The significance level was set at $P < 0.05$.

RESULTS: MVT was higher in males than females ($t = 7.02$, $P < 0.01$; Table 1). MVT was a significant predictor of RTD. When MVT was accounted for, no sex-related differences in pRTD and RTD in the windows 0-50, 0-100, and 0-150 ms from contraction onset were found ($t < 1.60$, $P > 0.12$; Table 1). Time to pRTD was shorter in males than females ($t = 3.58$, $P < 0.01$; Table 1). The number of identified motor units in females was 87 (~4 ± 2 per participant), vs. 71 identified in males (~6 ± 2 per participant, respectively). Values of MUDR at the onset of explosive contractions were not different between sexes ($t = 1.19$, $P = 0.23$; Figure 1).

Table 1: Maximal voluntary isometric torque and rate of torque development in males and females in explosive voluntary contractions.

Measures	Males	Females	*P* value
MVT (N·m)	41.9 ± 7.0	28.2 ± 4.1	< 0.01**
Normalised pRTD ($MVT \cdot s^{-1}$)	8.0 ± 2.0	7.7 ± 0.8	0.12
Time to pRTD (ms)	61 ± 12	74 ± 14	< 0.01**
Normalised RTD ($MVT \cdot s^{-1}$)			
0-50 ms	3.1 ± 0.8	3.2 ± 0.9	0.94
0-100 ms	4.7 ± 0.7	4.9 ± 0.6	0.40
0-150 ms	4.5 ± 0.4	4.7 ± 0.4	0.57

MVT, maximal voluntary torque; RTD, rate of torque development. *$P < 0.01$.

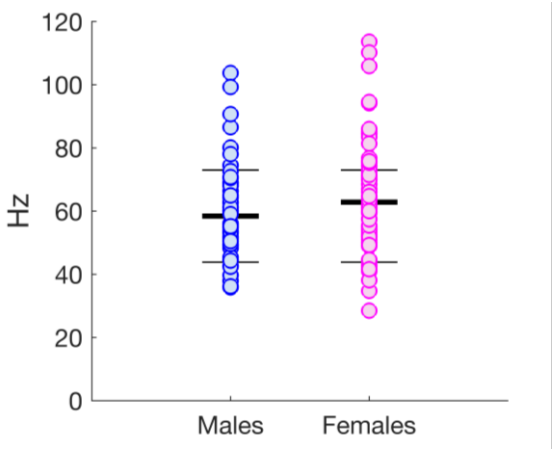

Figure 1: Motor units discharge rate at the onset of explosive contractions in males and females. Bars represent means and standard deviations. No sex-differences were found.

DISCUSSION: Males demonstrated greater MVT than females. This difference and its magnitude (maximal torque of females as percentage of that of males: 60-65%) is consistent with earlier reports and has been attributed mainly to a larger muscle mass, greater fibres cross-sectional area, and higher type II/type I muscle fibre area ratio in men compared to women (Nuzzo, 2024).

When MVT was accounted for in the linear regression models, measures of RTD were comparable between sexes. This corroborates findings from previous studies with measures of explosive strength between sexes from elbow flexors, knee flexors and extensors, and ankle dorsiflexors (Hannah et al., 2015; Inglis et al., 2017). Values of peak RTD as well as RTD in the windows 0-50, 0-100 and 0-150 ms from onset, are consistent with those reported from earlier research from ankle dorsiflexors (e.g., Del Vecchio et al., 2019).

According to previous research, pRTD was achieved between 60-80 ms from contraction onset (Klass et al., 2008). Measures of time to pRTD were shorter in males than females of ~13 ms. Such differences may be driven by the higher type II/type I muscle fibre area ratio in males in the tibialis anterior muscle (Nuzzo, 2024), as type II fibres exhibit higher rate of tension development than the type I counterpart (Schiaffino & Reggiani, 2011).

The number of identified motor units per participant was lower in females, a common finding for most previous studies regarding high-density EMG.

Previous research has reported differences in MUDR between sexes, but with the direction and magnitude depending on the muscle group examined and contraction intensity (Lulic-Kuryllo & Inglis, 2022). In isometric ankle dorsiflexions, values of MUDR in tibialis anterior were higher in females at relatively lower submaximal intensities (20-50% MVT; Lulic-Kuryllo & Inglis, 2022). At relatively higher submaximal intensities (50-80% MVT) mean MUDR was comparable between sexes, while it was higher in males than females in maximal efforts (Lulic-Kuryllo & Inglis, 2022). Across all contraction intensities, when strength-matched with males, females report greater MUDR (from tibialis anterior; Lulic-Kuryllo & Inglis, 2022). In the present study, values of MUDR at the beginning of explosive efforts were not statistically different between males and females. Future research should investigate MUDR during explosive efforts in muscles other than the tibialis anterior where not only the percentage of muscle CSA occupied by type II fibres is greater in males than females, but also the type II/I fibre ratio, such as typically shown from knee extensors (Nuzzo, 2024).

Methodological considerations. While decomposition of high-density EMG allowed studying the behaviour of motor units non-invasively in explosive contractions, this technique is known to have a relatively low yield of motor units number in females. To remedy for this, we recruited almost twice the number of females than males. Despite this, the known challenge of identifying motor units from high-density EMG decomposition in ballistic contractions remains. Notably, sex differences in tendon stiffness may have also played a role in the comparison between sexes in the present study, but whether tendon mechanical properties in ankle dorsiflexor

muscles are different between sexes remains to be determined. Future studies should ideally consider different phases of the menstrual cycle in females, as values of MUDR have been found to differ across menstrual phases (Piasecki et al., 2023). Lastly, MVT was included as a predictor in the linear mixed-effects models used. However, whether MVT should be treated as a confounder, mediator, or collider (Lederer et al., 2019) in the comparisons between sexes remains to be determined. Matching males and females for MVT represents a valuable approach to conduct sex-related comparisons.

Practical relevance. Explosive strength — the fundamental neuromuscular ability of producing the highest amount of force in the minimum time — is crucial for both athletic performance and clinical outcomes. When accounting for differences in maximal strength, males and females exhibit comparable capacities for rapid force production. This ability arises from the interplay of multiple elements along the neuromechanical continuum, from the motor cortex to muscle fibers. Within this continuum, female muscles typically exhibit a higher proportion of type I to type II fiber cross-sectional area compared to males, resulting in slower contraction kinetics. Given this, we hypothesized that females would compensate for their slower muscle force kinetics with a higher motor unit discharge rate at the onset of explosive contractions. However, contrary to our expectations, our findings reveal no significant sex differences in motor units discharge rate during explosive ankle dorsiflexions. This suggests that despite inherent differences in muscle fiber composition and contraction kinetics, the neuromuscular control of rapid force production remains similar between sexes. Consequently, these findings indicate that the neuromechanics of explosive strength may not require sex-specific considerations.

CONCLUSION: No sex differences were found in rapid torque production and motor units discharge rate during explosive isometric contractions of the ankle dorsiflexors between healthy males and females. This indicates that the neuromechanical determinants of explosive strength are comparable between sexes. Therefore, the neuromechanics of explosive strength may not require sex-specific considerations.

REFERENCES

Buckthorpe, M. & Roi, G.S. (2018). The time has come to incorporate a greater focus on rate of force development training in the sports injury rehabilitation process. *Muscles Ligaments Tendons* 7, 435-41.

Del Vecchio, A., Negro, F., Holobar, A., Casolo, A., Folland, J.P., Felici, F. & Farina, D. (2019). You are as fast as your motor neurons: speed of recruitment and maximal discharge of motor neurons determine the maximal rate of force development in humans. *J Physiol* 597, 2445-2456.

Hannah, R., Folland, J.P., Smith, S.L. & Minshull, C. (2015). Explosive hamstrings-to-quadriceps force ratio of males versus females. *Eur J Appl Physiol* 115, 837-47.

Hunter, S.K. & Senefeld, J.W. (2024). Sex differences in human performance. *J Physiol* 602, 4129-56.

Inglis, J.G., McIntosh, K. & Gabriel, D.A. (2017). Neural, biomechanical, and physiological factors involved in sex-related differences in the maximal rate of isometric torque development. *Eur J Appl Physiol* 117, 17-26.

Klass, M., Baudry, S. & Duchateau, J. (2008). Age-related decline in rate of torque development is accompanied by lower maximal motor unit discharge frequency during fast contractions. *J Appl Physiol* 104, 739-46.

Lulic-Kuryllo, T. & Inglis, J.G. (2022). Sex differences in motor unit behaviour: a review. *J Electromyog & Kinesiol* 66, 102689.

Maffiuletti, N., Aagaard, P., Blazevich, A.J., Folland, J., Tillin, N. & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *Eur J Appl Physiol* 116, 1091-1116.

McMahon, G. & Cook, J. (2024). Female tendons are from Venus and male tendons are from Mars, but does it matter for tendon health? *Sports Med* 54, 2467-74.

Nuzzo, J.L. (2024). Sex differences in skeletal muscle fibre types: a meta-analysis. *Clin Anat* 37, 81-91.

Piasecki, J., Guo, Y., Jones, E.J., Phillips, B.E., Stashuk, D.W., Atherton, P.J. & Piasecki, M. (2023). Menstrual cycle associated alteration of vastus lateralis motor unit function. *Sports Med Open,* 9, 97.

Ruggiero, L. & Gruber, M. (2024). Neuromuscular mechanisms for the fast decline in rate of force development with muscle disuse – a narrative review. *J Physiol* (Online ahead of print).

Schiaffino, S. & Reggiani, C. (2011). Fiber types in skeletal muscles. *Phys Rev* 91, 1447-1531.

Tillin, N.A., Jimenez-Reyes, P., Pain, M.T.G. & Folland, J.P. (2010). Neuromuscular performance of explosive power athletes versus untrained individuals. *Med Sci Sports Exerc* 42, 781-790.