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Clinical Case

POTENCIA, UMBRALES DE LACTATO Y EMG DEL TRÍCEPS BRAQUIAL EN UNA ATLETA DE ÉLITE EN SILLA DE RUEDAS: ESTUDIO DE CASO EN ERGÓMETRO DE RODILLOS

POWER OUTPUT, BLOOD LACTATE THRESHOLDS, AND TRICEPSBRACHII EMG IN AN ELITE WHEELCHAIR RACING ATHLETE: A CASE STUDY ON A ROLLER ERGOMETER

TÍTULO POTÊNCIA, LIMIARES DE LACTATO E EMG DO TRÍCEPS BRAQUIAL EM UMA ATLETA DE ELITE EM CADEIRA DE RODAS: ESTUDO DE CASO EM ERGÔMETRO DE ROLOS

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POTENCIA, UMBRALES DE LACTATO Y EMG DEL TRÍCEPS BRAQUIAL EN UNA ATLETA DE ÉLITE EN SILLA DE RUEDAS: ESTUDIO DE CASO EN ERGÓMETRO DE RODILLOS

POWER OUTPUT, BLOOD LACTATE THRESHOLDS, AND TRICEPSBRACHII EMG IN AN ELITE WHEELCHAIR RACING ATHLETE: A CASE STUDY ON A ROLLER ERGOMETER

RESUMEN

Objetivo: examinar la concordancia entre potencia estimada, lactato sanguíneo y actividad electromiográfica (EMG) del tríceps braquial en una atleta T54 de élite durante un test incremental en ergómetro de rodillos; Materiales y métodos: una competidora de categoría T54 realizó un protocolo incremental máximo en un sistema de rodillos calibrado. Se registraron la EMG de superficie del tríceps braquial y la concentración de lactato sanguíneo. La potencia mecánica se estimó mediante un modelo de resistencia a la rodadura (*coast-down)*; Resultados: se observaron puntos de inflexión simultáneos en la amplitud de la EMG y en la concentración de lactato a 20 km/h, coincidiendo con un marcado incremento de la demanda mecánica; Discusión: la fuerte concordancia entre la producción mecánica estimada y los marcadores fisiológicos internos refuerza el potencial de las evaluaciones en rodillo para identificar umbrales neuromusculares y metabólicos durante tareas de propulsión de los miembros superiores; Conclusiones: la estimación indirecta de la potencia en ergómetros de rodillos constituye una alternativa válida y accesible para la prescripción individualizada de cargas en deporte adaptado, favoreciendo la integración de herramientas de evaluación fisiológica en la monitorización del rendimiento de atletas con discapacidad.

Palabras clave: Atletas en silla de ruedas; potencia; umbral de lactato; rendimiento; electromiografía.

ABSTRACT

Objective: to examine the concordance between estimated power output, blood lactate concentration, and triceps brachii electromyographic (EMG) activity in a T54 elite athlete during an incremental roller ergometer test; Methods: a female T54 competitor performed a maximal incremental protocol on a calibrated roller ergometer. Surface EMG of the triceps brachii and capillary blood lactate concentration were recorded. Mechanical power was estimated through a coast-down modelling approach; Results: simultaneous inflection points in EMG amplitude and lactate concentration were observed at 20 km/h, coinciding with a steep increase in mechanical demand; Discussion: the strong agreement between estimated mechanical output and internal physiological markers reinforces the potential of roller-based assessments for identifying neuromuscular and metabolic thresholds during upper-limb propulsion tasks; Conclusions: indirect power estimation on roller ergometers provides a valid and accessible alternative for individualized load prescription in adapted sport, supporting the integration of physiological testing tools into performance monitoring of athletes with disabilities.

Keywords: wheelchair athletes; power output; lactate threshold; performance; electromyography; ergometry.

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TÍTULO

Potência, limiares de lactato e EMG do tríceps braquial em uma atleta de elite em cadeira de rodas: estudo de caso em ergômetro de rolos.

RESUMO

Objetivo: examinar a concordância entre a potência estimada, a concentração sanguínea de lactato e a atividade eletromiográfica (EMG) do tríceps braquial em uma atleta de elite da classe T54 durante um teste incremental em ergômetro de rolos; Métodos: uma competidora T54 realizou um protocolo incremental máximo em um ergômetro de rolos calibrado. Foram registrados o EMG de superfície do tríceps braquial e a concentração capilar de lactato sanguíneo. A potência mecânica foi estimada por meio de um modelo coast-down; Resultados: pontos de inflexão simultâneos na amplitude do EMG e na concentração de lactato foram observados a 20 km/h, coincidindo com um acentuado aumento da demanda mecânica.**;** Discussão: a forte concordância entre a potência mecânica estimada e os marcadores fisiológicos internos reforça o potencial das avaliações baseadas em rolos para identificar limiares neuromusculares e metabólicos durante tarefas de propulsão de membros superiores; Conclusões: a estimativa indireta de potência em ergômetros de rolos constitui uma alternativa válida e acessível para a prescrição individualizada de cargas no esporte adaptado, apoiando a integração de ferramentas de avaliação fisiológica no monitoramento do desempenho de atletas com deficiência.

Palabras-chave: Atletas em cadeira de rodas; potência; limiar de lactato; desempenho; eletromiografia; ergometria

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INTRODUCTIONComentario

Wheelchair racing athletes require a finely tuned balance of neuromuscular efficiency and physiological endurance to sustain high-performance propulsion while seated. Training and performance optimization in this population have gained increasing scientific attention, particularly in the context of load monitoring and individualized training prescriptions (Vanlandewijck et al., 2011). However, the specificity of wheelchair propulsion, characterized by intermittent contact, limited upper-limb musculature, and non-linear kinematics, makes the quantification of training load a complex task.

External load monitoring, typically quantified via power output applied to the hand rim, has emerged as a key metric to assess mechanical performance and energy expenditure during propulsion (van Dijk et al., 2024). Power-based metrics offer a reliable, objective measure that reflects the mechanical demands imposed on the athlete. Nonetheless, interpreting these metrics without considering the internal physiological responses may lead to incomplete or misleading conclusions about training stress and adaptation.

To complement external load metrics, physiological biomarkers such as blood lactate concentration and surface electromyography (EMG) are commonly used. Blood lactate offers insight into the metabolic stress and the shift from aerobic to anaerobic energy systems (Beneke et al., 2011), while EMG provides a window into the muscular activation patterns and neuromuscular effort during task execution (Reaz et al., 2006). In wheelchair racing, the triceps brachii, the main elbow extensor, plays a critical role in propulsion, making it a relevant muscle for EMG monitoring (Vanlandewijck et al., 2011).

Despite the relevance of these indicators, there is limited evidence on how power output, lactate levels, and EMG activity interact in wheelchair athletes during controlled incremental testing. The use of roller ergometers provides an ideal setting for such exploration, allowing for standardized assessments while recording detailed mechanical and physiological data (Janssen et al., 2025).

Building on our previous work, where we proposed and validated a low-cost methodology for estimating power output in Paralympic wheelchair athletes (Talayero et al., 2025), the present case study expands this framework by integrating physiological markers such as blood lactate and electromyography (EMG) to identify performance thresholds during roller ergometer testing.

We hypothesized that inflection points in triceps brachii electromyographic (EMG) activity and blood lactate concentration would coincide with a specific estimated power threshold, reflecting a coordinated shift in neuromuscular and metabolic responses. The triceps brachii was selected due to its primary role as the main elbow extensor during the push phase, its anatomical accessibility, and its high signal-to-noise ratio for surface EMG in athletes with spinal cord injury. The coast-down approach was chosen because it is non-invasive, cost-effective, and practical where direct instrumented power measurement is unavailable. The main limitations of this method—its dependence on accurate rolling resistance calibration and the absence of direct torque measurement—are acknowledged and discussed later in the manuscrip.

The aim of this case study was to examine whether the power output applied to the hand rim during an incremental test on a roller ergometer allows for the identification of physiological thresholds that are coherent with both blood lactate concentration and triceps brachii EMG activity in an elite female wheelchair racing athlete.

METHODS

This was a case study conducted with an elite T54 wheelchair racing athlete. The methodological approach combined a maximal incremental test on a roller ergometer with non-invasive monitoring of blood lactate and triceps brachii EMG. Power output was indirectly estimated using coast-down testing and dynamic modelling of rolling resistance to evaluate the concordance between mechanical and physiological thresholds.

Participants

A single elite female wheelchair athlete (44 years old), classified in category T54, voluntarily participated in this case study. She regularly competes in both track (400 m, 1500 m) and road races (marathon), at national and international levels. Prior to the study, she had completed a 10-day tapering phase without competitive activity to ensure metabolic recovery. She was cleared by medical staff to perform maximal effort tests. Written informed

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consent was obtained, and the study was approved by the institutional ethics committee.

Procedure

The protocol began with a standardized warm-up of 5 minutes at 7.5 km/h. The incremental test consisted of 3-minute stages at the following target speeds: 10, 12, 15, 17, 20, 22.5, and 25 km/h. Between stages, 15-second breaks were used to collect capillary blood samples from the earlobe to determine lactate concentration using a portable analyser (Lactate Scout, SensLab GmbH). Heart rate was continuously monitored with a Polar H10 chest strap sensor (Polar Electro Oy, Kempele, Finland). Perceived exertion was assessed after each stage using the Borg scale, and muscular activation was recorded via EMG. EMG electrodes were placed on the posterior aspect of each arm at the midpoint between the acromion and the olecranon. The test was terminated when the athlete could not maintain the prescribed speed (defined as a 15% drop in target speed for ≥15 seconds).

All tests were conducted in a climate-controlled laboratory (22 ± 1 °C; 45–55% relative humidity), maintaining constant environmental conditions throughout. The 3-min incremental stages were selected in accordance with validated protocols for wheelchair athletes (Janssen et al., 2025), providing an optimal balance between metabolic stabilization and temporal resolution for threshold detection

Power Estimation

Due to the absence of commercially available power meters for wheelchair roller benches, power output was estimated through a validated indirect method based on coast-down testing and dynamic modelling of rolling resistance.

Rolling resistance was determined on the roller bench using coast-down tests from fixed initial speeds (10, 15, and 20 km/h) and measuring the wheel revolutions. The resistive forces were calculated using the kinetic energy dissipation model and converted into torque and power values using the following relationship. For a rotating solid, the energy can be written as:

$$E_k = \frac{1}{2} * I * \omega^2$$
(1)

Where I is the inertia moment (kg·m^2) and ω is the rotating speed (rad/s). For a roller bench, the inertia of all the rotating masses should be considered (wheels plus the roller). The resistive force can be calculated as the energy divided by the distance travelled (wheel turns), that is a good approximation due to the absence of quadratic terms (aerodynamic effects). Finally, the power (W) required to maintain a given speed can be calculated by multiplying the force (N) by the speed (m/s). The power estimation is validated by direct accurate measurements based on the roller instant speed (Hernandez, 2025).

Electromyographic Measurement

Surface EMG activity of the triceps brachii was recorded throughout the test using a bipolar configuration. Surface EMG activity of the right triceps brachii was recorded throughout the test using wireless Trigno™ Avanti sensors (Delsys Inc., Natick, MA, USA). A bipolar configuration was employed with an inter-electrode distance of 2 cm, and placement followed SENIAM guidelines (Hermens et al., 2000). Signals were sampled at 1,000 Hz, band-pass filtered (20–450 Hz), full-wave rectified, and smoothed using a root mean square (RMS) algorithm with a 250 ms window. EMG activity was averaged over the final 30 seconds of each incremental stage, the standard deviation (SD) of EMG amplitude within each stage was computed across the 30 s time window used for RMS averaging. This SD represents the intra-stage variability of the EMG signal after full-wave rectification and smoothing, reflecting the stability of muscle activation under steady-state propulsion. Root mean square (RMS) values were not normalized to a maximal voluntary contraction (MVC) due to the difficulty of reproducing isometric contractions under realistic wheelchair propulsion conditions. However, electrode placement and amplifier gain were kept constant across all stages, following prior recommendation (Candotti et al. 2008), allowing valid relative comparisons between intensities

Data Analysis

Descriptive statistics were calculated for power, EMG, and lactate at each speed. Visual inspection of trends and thresholds was performed using combined plots. Power-speed relationships were fitted using second-order polynomials derived from resistance values. Concordance between physiological markers

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(EMG and lactate) and power output was evaluated to identify potential training thresholds.

Data processing and statistical analyses were performed using Microsoft Excel (Microsoft Corp., Redmond, WA, USA) and IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Blood lactate concentration, triceps brachii EMG amplitude, and estimated hand-rim power output increased progressively across the seven incremental stages (see Figure 1 and Table 1), exhibiting two distinct inflection points. The first inflection occurred at V5 (20 km/h), where blood lactate rose to 5.0 mmol·L⁻¹, indicating the onset of anaerobic metabolism; the second occurred at V7 (25 km/h), where lactate peaked at 9.3 mmol·L⁻¹. At V1 (10 km/h), blood lactate remained low (1.1 mmol·L⁻¹), with marginal increases at V2 (12 km/h; 1.3 mmol·L⁻¹) and V3 (15 km/h; 1.9 mmol·L⁻¹). A moderate rise was observed at V4 (17 km/h; 2.4 mmol·L⁻¹), followed by the pronounced inflection at V5, after which lactate continued to climb to 9.3 mmol·L⁻¹ at V7. Root-mean-square (RMS) values for triceps brachii EMG amplitudes remained relatively stable during the first four stages, rising markedly from V5 (20 km/h; 4.70×10^{-5} V) to 6.82×10^{-5} V at V6 (22.5 km/h) and peaking at 9.09×10^{-5} V at V7.

---------------------Table 1---------------------------

Table 1. Mean (± SD) blood lactate concentration, triceps brachii EMG RMS amplitude, and estimated power output at each incremental hand-rim propulsion stage

Stage	Speed (km/h)	LH (mmol·L⁻¹)	Power (W)	EMG (V·10-5) ± SD
V1	10.0	1,3	20,37	3,33 ± 0,12
V2	12.0	1,1	24,67	3,45 ± 0,14
V3	15.0	1,7	31,26	3,76 ± 0,18
V4	17.0	1,9	35,76	3,98 ± 0,21
V5	20.0	5	42,65	4,70 ± 0,25
V6	22.5	6	48,54	6,82 ± 0,28
V7	25.0	9,3	54,55	9,09 ± 0,30

V: velocity, LH: lactate concentration, EMG: electromyography

Note: single lactate values were obtained per stage; therefore, no standard deviation is reported for this variable. Estimated power values correspond to the mean value derived from the validated coast-down model based on the steady-state roller speed of each stage. EMG values are expressed as mean ± SD calculated over the final 30 s of each stage.

As shown in Table 1, lactate concentration values represent single capillary samples collected at the end of each stage, whereas EMG data were continuously recorded and expressed as mean ± SD over the final 30 s of each stage. Estimated power values correspond to the mean derived from the validated coast-down model based on the steady-state roller speed attained during each incremental step. Power output demonstrated a quasi-linear increase from 20.38 W at V1 to 54.56 W at 25 km/h (V7), consistent with the progressive rise in resistive force encountered on the roller ergometer. Polynomial modelling of power vs. speed confirmed an exponential-like increase in resistive force, consistent with previously reported coast-down models (Ott, 2020) and which have been replicated by us with the results shown in Figure 1.

The convergence of inflection points in both blood lactate and EMG amplitude occurred at 20 km/h (V5), corresponding to an estimated power output of approximately 37.28 W. No other stage demonstrated simultaneous, abrupt increases in both internal markers.

Bivariate correlations revealed strong associations between estimated power and blood lactate concentration ($r = 0.96$; $p < 0.01$), as well as between power and EMG amplitude ($r = 0.93$; $p < 0.01$). These findings confirm the coherence between

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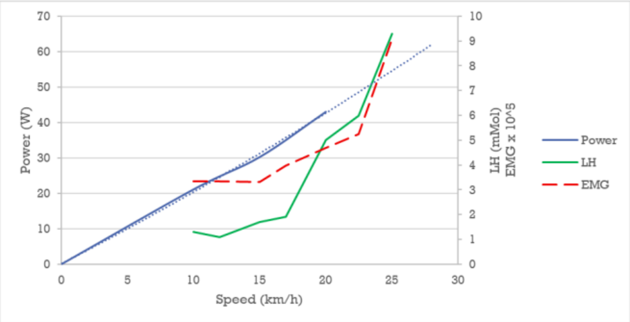
mechanical load estimation and internal physiological markers. Intra-stage variability, expressed as standard deviation, was below 5% for all variables, indicating high measurement consistency

--------------------Figure 1--------------------------

Figure 1. Relationship between speed, blood lactate concentration, triceps brachii EMG activity, and hand rim power output during the incremental roller test.



DISCUSSION

The present case study aimed to determine whether power output recorded on a roller ergometer could serve as a valid indicator for identifying physiological thresholds in a wheelchair racing athlete, using blood lactate and surface EMG of the triceps brachii as internal load markers. The findings demonstrate that, in this elite T54 wheelchair racer, a clear physiological and neuromuscular threshold emerges at 20 km/h, where both blood lactate concentration and triceps brachii EMG amplitude exhibit pronounced inflections at an estimated power output of ~37 W. This concurrent shift mirrors observations in other wheelchair propulsion studies showing that metabolic and neuromuscular markers co-locate at a critical intensity. For instance, it is reported that trunk kinematic alterations and increased muscle activation in T54 athletes coincide with lactate accumulation around similar propulsion (Guo et al., 2023). Likewise, it is observed that lactic acid rise and elevated triceps brachii EMG amplitude co-occur near the anaerobic threshold in elite versus novice wheelchair racers (Wieczorek et al., 2024). These converging data reinforce the notion that, in wheelchair racing, a velocity-dependent threshold exists where mechanical demand triggers both enhanced anaerobic glycolysis and increased motor unit recruitment.

As power output increased, blood lactate remained in the low-to-moderate range (1.1–2.4 mmol·L^{-1}) below 17 km/h, suggesting predominant reliance on oxidative metabolism. At 20 km/h (V5), lactate concentration rose sharply to 5.0 mmol·L^{-1}, reflecting a shift toward anaerobic energy contribution. This behaviour echoes findings in able-bodied cycling, where critical power (CP) and maximal lactate steady state (MLSS) thresholds correspond closely to transitions in energy system dominance (Vobejda et al., 2023). In our protocol, the 3-minute stages allowed lactate to accumulate sufficiently for clear identification of the threshold. It is consistent with studies that demonstrated that CP and MLSS differ by only a few watts when strict methodology is applied (Caen et al., 2024), the emergence of the lactate inflection at ~37 W confirms that the roller ergometer model accurately estimates metabolic demand in wheelchair propulsion. Therefore, the rise in lactate concentration from 1.9 to 5.0 mmol/L between V4 and V5 supports the notion that this stage corresponds to the anaerobic threshold. This is consistent with findings in able-bodied and para-athletes, where lactate accumulation marks a critical shift in energy system dominance (Beneke et al., 2011).

The triceps brachii, as the prime mover during the push phase in T54 athletes, is particularly sensitive to increasing propulsion demands. The significant increase in EMG amplitude beyond the 20 km/h threshold is in line with earlier electromyographic investigations that have identified this muscle as a discriminating factor of performance in elite athletes (Wieczorek et al., 2024; Chow & Levy, 2011). Interestingly, while most EMG-based research has focused on trunk musculature or multi-muscle activation (Guo et al., 2023), our single-muscle approach confirms that even localized EMG measurements may offer meaningful insights into workload. In the present study, triceps brachii EMG Root Mean Square (RMS) remained nearly constant (3.31–3.98×10^{-5} V) from 10 to 17 km/h, suggesting stable motor unit recruitment within predominantly low-intensity propulsion. The abrupt rise at 20 km/h

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(4.70×10^{-5} V) indicates increased neuromuscular effort to overcome augmented resistive forces. It is showed that, under incremental resistance exercise, EMG thresholds parallel lactate thresholds, confirming that slope changes signal the aerobic–anaerobic transition (Candotti et al., 2008). Similarly, in cycling, surface EMG thresholds align with ventilatory and lactate thresholds, reflecting coordinated neuromuscular and metabolic regulation (Sendra-Pérez et al., 2025). In the studied wheelchair athlete, the triceps brachii, as the primary elbow extensor during the push phase, increased recruitment at ~20 km/h to maintain higher propulsive forces, a pattern also noted by prior research (Requejo et al., 2008) in grip force analyses of wheelchair propulsion.

The tight coupling between EMG and lactate inflections suggests that, at this threshold, motor unit synchronization and firing rate escalate to meet the heightened mechanical demands, thereby increasing glycolytic flux. Such integrated neuromuscular–metabolic interplay has been documented in rehabilitation and sports settings, where EMG can serve as a noninvasive surrogate for metabolic thresholds (Voet et al., 2022). In wheelchair propulsion, this is particularly relevant since upper-limb musculature fatigue is a limiting factor; thus, simultaneous detection of EMG and lactate thresholds provides robust markers for training prescription.

Power output, estimated via coast-down modelling (see figure 1), exhibited a quasi-linear rise from 20 W at 10 km/h to 55 W at 25 km/h, but maintaining the typical parabolic behaviour of rolling resistance at low speeds with the equation y = 0.01013.x2 + 1.92408.x +0.12576 (R2=0.998). As there is no influence of aerodynamic drag on the roller bench, the parabola is smooth, but nevertheless adequately represents the rolling resistance in wheelchair racing, showing that resistive forces escalate exponentially with speed (Sprigle et al., 2022). In practice, identifying this “power threshold” is crucial for delineating training zones: intensities below threshold (Zone 1–2) emphasize aerobic endurance, while supra-threshold work (Zone 3) stimulates anaerobic and neuromuscular adaptations.

Therefore, power estimation methodology provided values that closely resemble those found in previous literature involving drum-based dynamometers (Ott, 2020). These indirect models, although less precise than integrated instrumented wheels, offer an accessible and reliable alternative for estimating mechanical output in field or lab conditions without sophisticated technology (Sprigle et al., 2022; de Groot et al., 2013).

The measured values also confirm the power estimation based on cost-down test (Hernandez, 2025); these findings are consistent with our previous work, where we validated a cost-effective methodology for estimating mechanical power output in Paralympic wheelchair athletes using coast-down tests on both track and roller ergometers (Talayero et al., 2025). In that study, indirect power estimations showed strong agreement with accelerometry-based measurements, reinforcing the validity of roller-based assessments as accessible tools for performance monitoring. The present case study extends those results by integrating physiological markers such as blood lactate and EMG, providing a more comprehensive framework to individualize training prescriptions.

In addition, the roller-based setting used in this study represents a controlled alternative to track-based testing, minimizing environmental variability and allowing for repeatable data collection. The drum’s mechanical properties were carefully calibrated, as recommended in studies evaluating rolling resistance (Sprigle et al., 2022). The validity of this approach is reinforced by the strong agreement between modelled and observed power-speed relationships, consistent with experimental dynamometry studies (de Groot et al., 2013; Cooper & De Luigi, 2014).

One notable limitation of this study is its single-subject design. While case studies offer detailed insight into individual physiology and biomechanics, the results cannot be generalized without caution. Nevertheless, for high-performance settings, individualized threshold detection may be more valuable than group-based estimations. Moreover, EMG signals are subject to intra-subject variability and require normalization methods (e.g., %MVC), which were not included in this protocol but should be considered in future designs (Reaz et al., 2006).

Another relevant consideration is the absence of trunk EMG and kinematic data. Prior studies have

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emphasized the role of trunk motion in propulsion effectiveness and force transmission to the hand rim (Guo et al., 2023); (Rodgers et al., 2000). Future iterations of this methodology could integrate full-body motion capture and multi-muscle EMG systems, as seen in high-level biomechanical analyses using Vicon and Delsys platforms (Guo et al., 2023; van Dijk et al., 2024).

Limitations

This study presents inherent limitations associated with its single-case design and the use of surface EMG. EMG recordings are susceptible to motion artifacts, changes in skin impedance, and minor electrode displacement. Although these effects were minimized through visual inspection and digital filtering, they cannot be completely eliminated. Additionally, the absence of normalization to MVC prevents direct comparison of absolute amplitudes across subjects. The lactate threshold itself may vary widely between individuals and should not be interpreted as a universal value (e.g., fixed at 4–5 $mmol \cdot L^{-1}$). Therefore, the observed value (5.0 $mmol \cdot L^{-1}$) should be considered an individualized inflection point rather than a general reference.

CONCLUSIONS

This single-case study demonstrates that estimated power output on a roller ergometer can serve as a valid indicator for identifying individual physiological thresholds in T54 athletes. Although findings are limited to a single elite competitor, they provide a solid experimental basis for further research with larger cohorts. Practically, the power values associated with concurrent EMG-lactate inflection points (~37 W) may guide individualized training-zone prescription, enabling more precise load management in upper-limb propulsion sports.

The alignment between neuromuscular and metabolic markers supports the integration of power-based monitoring systems in wheelchair sports performance evaluation, especially when invasive or high-cost alternatives are unavailable. Moreover, localized EMG analysis of key propulsion muscles such as the triceps brachii may serve as a viable surrogate for broader kinematic and neuromuscular assessments.

Future studies should explore this approach in larger cohorts and integrate trunk kinematics and EMG to develop a more complete profile of performance determinants in wheelchair racing.

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