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BIODYNAMIC VARIABLES AND COMPETITIVE PERFORMANCE IN HANDBIKE AND PARALYMPIC POWERLIFTING ATHLETES: A PILOT STUDY

VARIÁVEIS BIODINÂMICAS E DESEMPENHO
COMPETITIVO EM ATLETAS DE HANDBIKE E POWERLIFTING
PARALÍMPICO: UM ESTUDO PILOTO

VARIABLES BIODINÂMICAS Y RENDIMIENTO
COMPETITIVO EN ATLETAS DE HANDBIKE Y POWERLIFTING
PARALÍMPICO: UN ESTUDIO PILOTO

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ABSTRACT

Performance in Paralympic sport depends on the interaction among neuromuscular, metabolic, and structural variables. The identification of biodynamic markers associated with competitive performance remains a challenge, particularly in sports that rely predominantly on the upper limbs. This study investigated the association between biodynamic variables and competitive performance in Handbike and Paralympic Powerlifting parathletes. A cross-sectional study was conducted with 10 high-performance parathletes (9 men and 1 woman), including 5 Paralympic Powerlifting athletes and 5 Handbike athletes. Body composition was assessed by DXA, isometric strength by handgrip dynamometry, dynamic strength by medicine ball throw, and upper-limb anaerobic power by the Wingate test. Performance was determined using official competition rankings. In the total sample, mean power ($r = 0.716$; $p = 0.020$) and peak power ($r = 0.648$; $p = 0.043$) showed significant associations with competitive ranking. Gynoid fat percentage was also associated with performance ($r = 0.667$; $p = 0.035$), suggesting an influence of non-contractile body mass on competitive efficiency. In the sport-specific analysis, training experience was strongly correlated with performance in Paralympic Powerlifting ($r = 0.892$; $p = 0.042$), whereas lower-limb bone mineral density was associated with performance in Handbike ($r = 0.999$; $p = 0.017$). Upper-limb anaerobic power emerges as a potential integrative marker of competitive performance in Paralympic sports dependent on upper-limb function. Regional body-composition aspects and structural variables also demonstrate sport-specific relevance. These findings provide practical support for monitoring, training prescription, and the development of evaluation models that are more sensitive to the demands of high-performance Paralympic sport.

KEYWORDS

Paralympic sport; anaerobic power; body composition; competitive performance; functional assessment.

RESUMO

O desempenho no esporte paralímpico depende da interação entre variáveis neuromusculares, metabólicas e estruturais. A identificação de marcadores biodinâmicos associados ao desempenho competitivo ainda representa um desafio, especialmente em modalidades dependentes dos membros superiores. Este estudo investigou a associação entre variáveis biodinâmicas e o desempenho competitivo em paratletas de Handbike e Powerlifting Paralímpico. Estudo transversal com 10 paratletas de alto rendimento (9 homens e 1 mulher), sendo 5 do Powerlifting Paralímpico e 5 do Handbike. Foram avaliadas composição corporal por absorciometria por raios X de dupla energia DXA, força isométrica (preensão manual), força dinâmica (arremesso de Medicine Ball) e potência anaeróbica de membros superiores por teste Wingate Anaerobic Test. O desempenho foi determinado pelo ranking oficial das competições. Na amostra total, a potência média ($r = -0,716$; $p = 0,020$) e a potência máxima ($r = -0,648$; $p = 0,043$) apresentaram associações significativas com o ranking competitivo. A porcentagem de gordura ginóide também se associou ao desempenho ($r = -0,667$; $p = 0,035$), sugerindo influência da massa corporal não contrátil na eficiência competitiva. Na análise por modalidade, o tempo de prática correlacionou-se fortemente com o desempenho no Powerlifting Paralímpico ($r = -0,892$; $p = 0,042$), enquanto a densidade mineral óssea dos membros inferiores associou-se ao desempenho no Handbike ($r = -0,999$; $p = 0,017$). A potência anaeróbica de membros superiores destaca-se como potencial marcador integrativo do desempenho competitivo em modalidades paralímpicas dependentes dos membros superiores. Aspectos regionais da composição corporal e variáveis estruturais também demonstram relevância específica por modalidade. Os achados fornecem subsídios aplicáveis ao monitoramento, à prescrição de treinamento e ao desenvolvimento de modelos avaliativos mais sensíveis às demandas do esporte paralímpico de alto rendimento.

PALAVRAS-CHAVE

Esporte paralímpico; Potência anaeróbica; Composição corporal; Desempenho competitivo; Avaliação funcional.

RESUMEN

El rendimiento en el deporte paralímpico depende de la interacción entre variables neuromusculares, metabólicas y estructurales. La identificación de marcadores biodinámicos asociados al rendimiento competitivo aún representa un desafío, especialmente en modalidades dependientes de los miembros superiores. Este estudio investigó la asociación entre variables biodinámicas y el rendimiento competitivo en paradeportistas de Handbike y Powerlifting Paralímpico. Estudio transversal con 10 paradeportistas de alto rendimiento (9 hombres y 1 mujer), siendo 5 de Powerlifting Paralímpico y 5 de Handbike. Se evaluaron la composición corporal mediante DXA, la fuerza isométrica (prensión manual), la fuerza dinámica (lanzamiento de medicine ball) y la potencia anaeróbica de los miembros superiores mediante la prueba de Wingate. El rendimiento fue determinado por el ranking oficial de las competiciones. En la muestra total, la potencia media ($r = -0.716$; $p = 0.020$) y la potencia máxima ($r = -0.648$; $p = 0.043$) presentaron asociaciones significativas con el ranking competitivo. El porcentaje de grasa ginoide también se asoció con el rendimiento ($r = -0.667$; $p = 0.035$), sugiriendo la influencia de la masa corporal no contráctil en la eficiencia competitiva. En el análisis por modalidad, el tiempo de práctica se correlacionó fuertemente con el rendimiento en el Powerlifting Paralímpico ($r = -0.892$; $p = 0.042$), mientras que la densidad mineral ósea de los miembros inferiores se asoció con el rendimiento en Handbike ($r = -0.999$; $p = 0.017$). La potencia anaeróbica de los miembros superiores se destaca como un potencial marcador integrador del rendimiento competitivo en modalidades paralímpicas dependientes de los miembros superiores. Aspectos regionales de la composición corporal y variables estructurales también demuestran relevancia específica según la modalidad. Los hallazgos aportan evidencias aplicables al monitoreo, la prescripción del entrenamiento y el desarrollo de modelos de evaluación más sensibles a las demandas del deporte paralímpico de alto rendimiento.

PALABRAS CLAVE

Deporte paralímpico; Potencia anaeróbica; Composición corporal; Rendimiento competitivo; Evaluación funcional.

1 INTRODUCTION

High-performance Paralympic sport has grown substantially in recent decades, accompanied by advances in training processes, functional assessment, and sport classification. At the same time, scientific interest in understanding the determinants of competitive performance in parathletes has increased, recognizing that traditional physical-assessment models developed for athletes without disabilities are not always directly applicable to this population. In this context, investigations that

consider the physiological, neuromuscular, and biomechanical specificities of Paralympic sport are essential to support more effective and individualized assessment and training practices.

In Paralympic sports predominantly dependent on the upper limbs, such as Handbike and Paralympic Powerlifting, performance emerges from the interaction of multiple physiological, neuromuscular, and biomechanical components (FLETCHER *et al.*, 2021; GEE *et al.*, 2021). In handbike, cyclic propulsion with the upper limbs imposes high metabolic and mechanical demands, requiring not only force and power production but also the ability to sustain performance over time, particularly in speed and endurance events (STEPHENSON *et al.*, 2020; NEVIN *et al.*, 2022). In Paralympic Powerlifting, although competitive success is determined by maximal bench-press strength, performance also depends on proximal stability, trunk control, and efficient neuromuscular activation throughout the different phases of the movement (AIDAR *et al.*, 2021; SANTOS *et al.*, 2023).

Among the physical variables associated with performance in these sports, upper-limb anaerobic power stands out as an important functional marker. Mean power, neuromuscular represents the ability to sustain high levels of power output during short-duration efforts, reflecting neuromuscular and metabolic efficiency (LOVELL *et al.*, 2013; BUHMANN *et al.*, 2024). In sports requiring repeated accelerations, pace changes, and maintenance of speed or force under fatigue, this capacity may play a decisive role in competitive performance (KRAAIJENBRINK *et al.*, 2020; STEPHENSON, *et al.*, 2020). Despite its theoretical relevance, the application and interpretation of anaerobic power in Paralympic sport remain limited, with few studies examining its direct association with performance across different modalities.

Beyond neuromuscular capacity, body composition has been recognized as an important factor in sports performance, particularly when analyzed regionally. In parathletes, body-mass distribution may exert functional influences distinct from those observed in athletes without disabilities, since segments with reduced or passive participation in the sport movement may affect energy cost, postural stabilization demands, and overall mechanical efficiency (KU *et al.*, 2012; CAVEDON, *et al.*, 2025). Gynoid fat percentage may therefore act as an indicator of non-contractile body mass distribution (KU *et al.*, 2012), whereas lower-limb bone mineral density may reflect structural and mechanical-use characteristics even in upper-limb-dominant sports (HILKENS *et al.*, 2023; FLORVÅG *et al.*, 2025).

Although these components have strong physiological foundations, integrated investigations examining upper-limb anaerobic power, body composition, and competitive performance in Paralympic athletes remain scarce. Most available evidence focuses on non-disabled populations or analyzes physical variables in isolation. Additionally, the functional heterogeneity characteristic of this population highlights the need for exploratory studies aimed at identifying potential biodynamic performance markers.

Therefore, the aim of this study was to investigate the association between biodynamic variables — including upper-limb anaerobic power, body composition, and muscular strength — and competitive performance in Handbike and Paralympic Powerlifting parathletes. Additionally, sport-specific analyses were conducted considering the functional and biomechanical characteristics of each sport.

2 MATERIALS AND METHODS

2.1 STUDY DESIGN AND PARTICIPANTS

This cross-sectional study included 10 high-performance parathletes (nine men and one woman) with a median age of 39.0 years (min-max: 26.0–52.0). All participants were active athletes affiliated with sport federations, with at least one year of experience and participation in official national competitions.

The sample was stratified by sport: five Paralympic Powerlifting athletes (four men and one woman) and five male Handbike athletes from functional classes H3 (n=4) and H4 (n=1).

Participants were recruited by convenience sampling from sports clubs and provided written informed consent. Inclusion criteria were:

- (i) physical impairment according to Brazilian Paralympic Committee classification;
- (ii) regular training and competition participation.

Athletes with acute injuries, clinical conditions preventing testing, or absence from any evaluation stage were excluded.

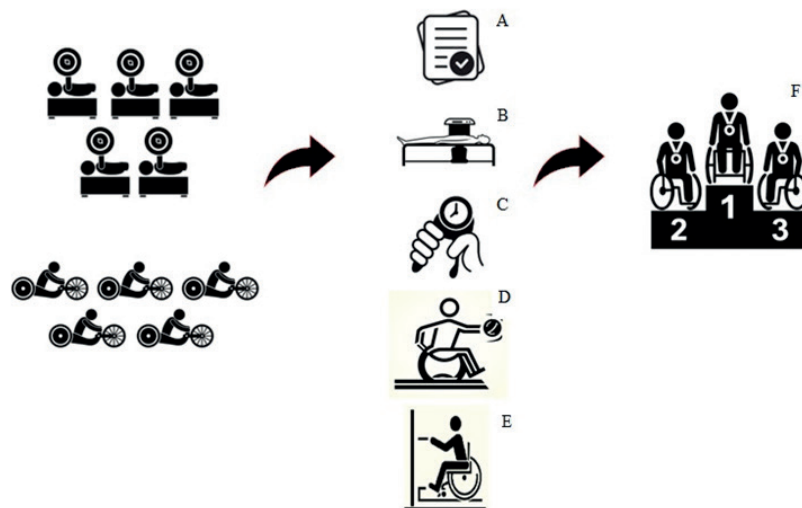
Assessments were conducted 15 days before official competitions (Meeting Paralímpico Loterias Caixa, a Brazilian Paralympic competition — Powerlifting; Copa Brasil de Paraciclismo, a Brazilian Paracycling competition — Handbike). The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the Federal University of Rio Grande do Norte (approval #: #83312924.5.0000.5537).

2.2 PROCEDURES

All assessments were conducted in a controlled and accessible laboratory during a single session lasting approximately 50 minutes per participant. Athletes were instructed to wear light clothing, empty their bladder before testing, and avoid intense exercise on the day of data collection.

Anthropometry and body composition (DXA) were assessed first. After a specific upper-limb warm-up, isometric strength (handgrip) and dynamic strength (medicine ball throw) tests were performed. Participants then completed a 5-minute familiarization and warm-up on an arm-cycle ergometer followed by the upper-limb Wingate test. All procedures followed standardized protocols.

Figure 1 - Study procedures - A: Informed consent form; B: Anthropometry and body composition assessment by DXA; C: Handgrip strength test; D: Medicine ball throw test; E: Upper-limb adapted Wingate test; F: Official competition ranking result.



2.3 ANTHROPOMETRY

Fat mass, lean mass, total body fat percentage, regional fat distribution (including gynoid fat percentage), and bone mineral density (total and regional) were assessed by dual-energy X-ray absorptiometry (DXA; LUNAR®/GE PRODIGY, enCORE Software version 15.0). Whole-body scans were performed (76 kV, 0.150 mA, radiation dose of 0.4 μ Gy. Body mass was measured using Filizola® or Micheletti® wheelchair scales, and height was measured using a Sanny® stadiometer or a conventional stadiometer when needed.

2.4 ISOMETRIC AND DYNAMIC UPPER-LIMB STRENGTH

Isometric strength was measured using a Jamar® handgrip dynamometer. Participants performed three maximal attempts with each hand (60-second intervals). The highest value (Kgf) was recorded.

Dynamic strength was assessed using the seated medicine ball throw test (2 kg). Three attempts were performed, and the greatest distance (cm) was recorded.

2.5 UPPER-LIMB ANAEROBIC POWER

Anaerobic power was evaluated using an arm-cycle ergometer (Technogym® Excite+ Top 700i) with a 30-second Wingate Anaerobic Test following a 5-minute warm-up. Resistance was automatically determined by the equipment software according to manufacturer specifications, considering sex, age, and body mass. Peak power, mean power, relative peak power, and relative mean power were recorded.

2.6 COMPETITIVE PERFORMANCE

Performance was determined from official rankings provided by the Brazilian Paralympic Committee and the Brazilian Cycling Confederation (CBC, 2024; CPB, 2024). Rankings were converted into an ordinal scale, with first place representing the best performance.

2.7 STATISTICAL ANALYSIS

Normality was tested using Shapiro–Wilk and skewness/kurtosis tests. Data were expressed as median, interquartile range, minimum, and maximum. Spearman’s rho correlations were calculated and interpreted by magnitude (SCHOBER *et al.*, 2018). Analyses were performed using Jamovi® (v2.3.28), with $p < 0.05$. Post-hoc statistical power and required sample size were calculated using G*Power® (v3.1). Sport-specific subanalyses were conducted.

3 RESULTS

The sample characteristics are presented in Table 1, both for the overall group and stratified by sport modality, including age, time since disability onset and type of disability, sport practice duration, body composition, upper-limb strength, and anaerobic power variables.

Table 1 - Sample characterization.

Variable	Total sample (n=10)		Powerlifting (n=05)		Handbike (n=05)	
	Median (IQR)	Min-Max	Median (IQR)	Min- Max	Median (IQR)	Min-Max
Age (years)	39,0 (11,7)	26,0; 52,0	30,0 (2,0)	26,0; 41,0	42,0 (1,0)	37,0; 52,0
Time with disability (years)	11,5 (16,7)	5,0; 37	11,0 (17,0)	5,0; 30,0	12,0 (16,0)	8,0; 37,0
Time in the sport (years)	3,0 (1,5)	2,0; 6,0	3,0 (1,0)	2,0; 4,0	3,0 (2,0)	2,0; 6,0
Supine height (cm)	172,0 (12,2)	140; 180	168,0 (14,0)	156,0; 180,0	173,0 (4,0)	140,0; 180,0
Total mass (kg)	64,1 (20,2)	47,4; 98	62,6 (22,0)	58,5; 98,0	65,7 (13,2)	47,4; 83,3
% FAT	31,6 (13,3)	19,7; 49,4	30,6 (15,0)	24,3; 49,4	32,6 (13,8)	19,7; 39,0
Total BMD (g/cm ²)	1,09 (0,09)	0,9; 1,50	1,13 (0,08)	1,05; 1,50	1,07 (0,18)	0,90; 1,34
Right handgrip (kgf)	45,2 (14,5)	32,0; 60,0	56,0 (11,0)	40,5; 60,0	41,0 (5,5)	32,0; 52,5

Variable	Total sample (n=10)		Powerlifting (n=05)		Handbike (n=05)	
	Median (IQR)	Min-Max	Median (IQR)	Min- Max	Median (IQR)	Min-Max
Left handgrip (kgf)	46,7 (15,3)	23,0; 58,0	49,0 (20,5)	37,0; 58,0	46,5 (13,5)	23,0; 53,5
Maximum throw (cm)	539,7 (50,6)	430,0; 930	573,0 (160,0)	434,0; 930,0	533,0 (22,0)	430,0; 552,5
Maximum power (W)	325,5 (85,0)	198,0; 377,0	345,0 (100,0)	198,0; 377,0	323,0 (35,0)	212,0; 342,0
Relative maximum power (W/kg)	4,2 (0,89)	3,36; 6,50	4,0 (0,66)	3,36; 6,50	4,51 (0,66)	3,95; 6,22
Average power (W)	265,0 (46,0)	177,0; 316,0	275 (45,0)	177,0; 316,0	258,0 (41,0)	194,0; 279,0
Relative average power (W/kg)	3,6 (0,96)	3,00; 4,83	3,28 (0,58)	3,0; 4,83	4,12 (0,89)	3,28; 4,70
Type of disability	n	%	n	%	n	%
Congenital	2,0	20,0	1,0	10,0	1,0	10,0
Acquired	8,0	80,0	4,0	40,0	4,0	40,0

Kg – kilogram, Kgf - kilogram-force, g/cm² – grams per square centimeter, g – gram, % Fat – Percentage of body fat, cm – centimeter, W – Watts, W/Kg – Watts per kilogram

Table 2 presents the correlation analysis considering the total sample (Handbike and Paralympic Powerlifting athletes), highlighting significant associations between competitive ranking and mean power ($r = 0.716$; $p = 0.020$), peak power ($r = 0.648$; $p = 0.043$), and gynoid fat percentage ($r = 0.667$; $p = 0.035$). The remaining biodynamic variables did not show statistically significant correlations with competitive performance.

Table 2 - Correlation between biodynamic variables and competitive performance

Variable	r	p
Time in sport (years)	-0.358	0.300
Body mass (kg)	-0.122	0.700
Right Handgrip (kgf)	-0.098	0.700
Left Handgrip (kgf)	-0.083	0.800

Variable	r	p
Medicine ball throw (cm)	-0.349	0.300
Peak power (W)	-0.648	0.043
Relative peak power (W/kg)	-0.251	0.400
Mean power (W)	-0.716	0.020
Relative mean power (W/kg)	-0.169	0.600
Gynoid fat (%)	-0.667	0.035
Total body fat (%)	-0.495	0.100
Arm BMD (g/cm ²)	-0.012	0.900
Leg BMD (g/cm ²)	0.141	0.600
Total BMD (g/cm ²)	-0.061	0.800

kg — kilogram; g — gram; Kgf - kilogram-force, %BF — body fat percentage; cm — centimeter; W — watts; W/kg — watts per kilogram; BMD — bone mineral density; g/cm² — grams per square centimeter.

When the analyses were performed stratified by sport modality (Table 3), a strong correlation was observed in **Paralympic Powerlifting** between competitive ranking and **time in sport practice** ($r = 0.892$; $p = 0.042$). In **Handbike**, a very strong correlation was identified between **competitive performance** and **lower-limb bone mineral density** ($r = 0.999$; $p = 0.017$). The remaining variables did not show statistically significant associations.

Table 3. Correlation between biodynamic variables and competitive ranking stratified by sport modality

Variable	Paralympic Powerlifting (n = 5)	p	Handbike – Sprint events	p	Handbike – Endurance events	p
	r		r		r	
Time in sport (years)	-0.892	0.042	-0.410	0.400	0.103	0.800
Body mass (kg)	-0.667	0.200	0.600	0.300	-0.900	0.083
Right Handgrip strength (kgf)	0.237	0.700	0.100	0.900	-0.400	0.500
Left Handgrip strength (kgf)	0.026	0.900	0.200	0.700	-0.300	0.600
Medicine ball throw (cm)	-0.564	0.300	-0.100	0.900	-0.100	0.900
Peak power (W)	-0.667	0.200	-0.100	0.900	-0.100	0.900

Variable	Paralympic Powerlifting (n = 5) r	p	Handbike – Sprint events r	p	Handbike – Endurance events r	p
Relative peak power (W/kg)	-0.410	0.400	-0.900	0.080	0.600	0.300
Mean power (W)	-0.821	0.080	-0.300	0.600	-0.300	0.600
Relative mean power (W/kg)	-0.154	0.800	-0.900	0.080	0.600	0.300
Gynoid fat (%)	-0.872	0.054	-0.300	0.600	0.200	0.700
Total body fat (%)	-0.667	0.200	-0.100	0.900	-0.100	0.900
Arm BMD (g/cm²)	-0.205	0.700	0.100	0.900	-0.400	0.500
Leg BMD (g/cm²)	0.051	0.900	0.500	0.400	-0.999	0.017
Total BMD (g/cm²)	-0.667	0.200	0.600	0.300	-0.900	0.083

Kg – kilogram, g – gram, Kgf - kilogram-force, cm – centimeter, W – Watts, W/Kg – Watts per kilogram, BMD – bone mineral density, g/cm² – grams per square centimeter.

4 DISCUSSION

The present study investigated the association between biodynamic variables and competitive performance in Handbike and Paralympic Powerlifting parathletes. The main findings indicated significant associations between competitive ranking and both mean and peak upper-limb power, as well as gynoid fat percentage. Furthermore, sport-stratified analyses revealed an association between training experience and performance in Paralympic Powerlifting, and between lower-limb bone mineral density and performance in Handbike. Conversely, no significant associations were observed between competitive performance and isometric strength, dynamic strength, or relative power variables.

4.1 UPPER-LIMB ANAEROBIC POWER AND COMPETITIVE PERFORMANCE

Upper-limb anaerobic power showed a significant association with competitive performance, with mean power emerging as the variable most strongly related to sport ranking (Table 2). Peak power reflects the capacity to generate high levels of force in a short period of time, whereas mean power represents the ability to sustain performance throughout the effort (LOVELL *et al.*, 2013; BUHMANN *et al.*, 2024). In Paralympic sports that predominantly rely on upper-limb function, the ability to maintain effort is decisive.

In Paralympic Powerlifting, mean power may reflect the parathlete’s efficiency in organizing and sustaining neuromuscular activation of agonist and stabilizing muscles across different phases of the movement (controlled descent, mandatory pause, and concentric phase) (SANTOS *et al.*, 2023). During a competitive attempt, the athlete must maintain proximal rigidity, scapular stability, and su-

efficient intermuscular coordination to efficiently transfer force to the bar, particularly under high loads (TELES *et al.*, 2021; AIDAR *et al.*, 2021; AIDAR *et al.*, 2022a).

In handbike, this capacity plays a significant role, as athletes must sustain high levels of force production and angular velocity during both sprint and endurance events while coping with peripheral fatigue, high metabolic demand, and the need for efficient intermuscular coordination (STEPHENSON *et al.*, 2020; NEVIN *et al.*, 2022). Thus, mean power becomes a relevant functional indicator of the athlete's ability to sustain effective propulsion, particularly during acceleration, pace transitions, and maintenance of average race speed (KRAAIJENBRINK *et al.*, 2020; STEPHENSON *et al.*, 2020).

The results of the present study align with recent evidence in paracycling showing that mean power obtained in a short-duration sprint test (20 seconds) is strongly associated with time-trial performance ($\approx 0.029\text{--}0.030$ km/h per Watt) (NOOIJEN *et al.*, 2021). Similarly, in Paralympic Powerlifting, studies (AIDAR *et al.*, 2022b; GUERRA *et al.*, 2022) have demonstrated very strong associations between velocity- and power-related variables in the bench press and performance, typically expressed as competitive one-repetition maximum (1RM). These findings indicate that although performance in the sport is determined by maximal strength, the ability to generate power across different intensities constitutes a relevant mechanical component of performance.

Sports performance in both Paralympic Powerlifting and Handbike depends on upper-limb neuromuscular efficiency (NEVIN *et al.*, 2022; SILVERTHORNE, *et al.*, 2025), which may explain the relevance of mean power observed in this study. These findings are consistent with previous evidence identifying upper-limb anaerobic power as a variable associated with performance in Paralympic modalities predominantly dependent on upper-limb action (CAVEDON *et al.*, 2021b; GEE *et al.*, 2021; BUHMANN *et al.*, 2024; SIMENKO *et al.*, 2024).

The stronger association observed between mean power and competitive performance when considering the total sample may be explained by the greater physiological and functional variability among the parathletes evaluated. In this context, upper-limb mean power acts as an integrative marker of neuromuscular efficiency common to sports that rely primarily on the production and maintenance of force by the upper limbs, regardless of sport-specific movement characteristics. Conversely, when analyses were stratified by modality, correlation magnitudes decreased, which may be related to both sample size and lower within-group variability. Additionally, variables with greater technical and functional specificity may exert a stronger relative influence on performance within each modality, reducing the isolated contribution of mean power.

4.2 BODY COMPOSITION AND COMPETITIVE PERFORMANCE

In the present study, gynoid fat percentage was significantly associated with competitive performance. The analysis of regional fat distribution has been considered more informative than global measures because it more specifically reflects the functional demands imposed by the sport-specific movement, particularly in Paralympic sport (CAVEDON *et al.*, 2021a; CAVEDON *et al.*, 2025). In modalities predominantly dependent on upper-limb function, indirect evidence suggests that increased inert body mass may be associated with higher overall energy expenditure and greater demands for stabilization and postural control (LEDIN *et al.*, 2004; KU *et al.*, 2012; CIEŚLIŃSKA-ŚWIDER *et al.*, 2022).

In Paralympic Powerlifting, the technical movement is performed in the supine position and strongly depends on proximal stability, trunk control, and efficient force transmission from the upper limbs to the barbell (IPC, 2023). Although no studies to date have directly examined the influence of gynoid fat on performance in this modality, indirect evidence indicates that increased non-contractile body mass may impair the force-to-body-mass ratio and elevate postural control demands (LEDIN *et al.*, 2004; GOLAS *et al.*, 2017). Additionally, changes in body positioning on the bench may influence mechanical lever arms and movement stability, increasing neuromuscular control requirements to maintain whole-body rigidity (GOLAS *et al.*, 2017; FLETCHER *et al.*, 2021). This scenario may also interfere with the athlete's weight category within the sport.

In handbike, characterized by cyclic upper-limb propulsion in a seated or reclined position, body fat distribution may have relevant functional implications for competitive performance (KRAAIJENBRINK *et al.*, 2020; NEVIN *et al.*, 2022). Although no studies have directly evaluated the influence of gynoid fat in handbike parathletes, indirect evidence from research on body composition, energy cost, and mechanical efficiency suggests that increased non-contractile body mass tends to elevate the overall energy cost of movement (SANTUZ *et al.*, 2018; WALSH; LOW, 2021).

In this context, a higher percentage of gynoid fat may indirectly affect performance, as this region contributes substantially to the total mass displaced during competition without actively participating in propulsion (KRAAIJENBRINK *et al.*, 2020; STEPHENSON *et al.*, 2020). Consequently, it increases trunk and hip stabilization demands, particularly during accelerations, pace transitions, and terrain variations (KRAAIJENBRINK *et al.*, 2020; STEPHENSON *et al.*, 2020; NEVIN *et al.*, 2022). Furthermore, increased inert mass may compromise propulsion mechanical efficiency, requiring greater upper-limb power output to maintain velocity (STONE *et al.*, 2020; TUROŃ-SKRZYPÍŃSKA *et al.*, 2020). In endurance events, this effect may be cumulative, contributing to earlier fatigue onset, reduced propulsion efficiency, and impaired maintenance of average race speed (STEPHENSON *et al.*, 2020).

In Paralympic athletes, gynoid fat should be understood not merely as a regional adipose compartment but as a functional component of total body mass capable of influencing energy cost, postural stability, and neuromuscular efficiency. In sports such as Paralympic Powerlifting and Handbike, in which the upper limbs play a central role in force and power production, a higher percentage of gynoid fat may represent an additional challenge to competitive effectiveness, acting as an indirect marker of the relationship between functional mass and inert mass.

4.3 SPORT-SPECIFIC FINDINGS

In Paralympic Powerlifting, a significant association was observed between years of sport practice and competitive performance. Although this finding should be interpreted with caution due to the pilot nature of the study, it is physiologically plausible and consistent with the highly technical demands of the modality. Performance in the Paralympic bench press depends not only on maximal force production but also on motor pattern consolidation, bar trajectory control, and efficient neuromuscular activation throughout the different movement phases — aspects that tend to improve with greater sport-specific experience (SANTOS *et al.*, 2023; SILVERTHORNE *et al.*, 2025).

Evidence in the literature indicates that sport experience is associated with reduced technical variability, greater movement stability, and improved neuromuscular efficiency in tasks with high mechanical demand, particularly in maximal-strength sports (TELES *et al.*, 2021; AIDAR *et al.*, 2022b). In Paralympic athletes, this process may be even more relevant due to the need for compensatory strategies, greater reliance on trunk control, and progressive adaptation to the specific demands of the competitive bench press (SANTOS *et al.*, 2023). Thus, years of practice may act as an indirect marker of technical and neuromuscular maturation, contributing to more consistent performance in Paralympic Powerlifting.

In Handbike, a significant association was observed between competitive performance and lower-limb bone mineral density. Although the lower limbs do not actively participate in propulsion in this modality, this finding may reflect relevant structural and functional aspects of performance (KRAAIJENBRINK *et al.*, 2020; NEVIN *et al.*, 2022). Bone mineral density has been considered an indirect marker of mechanical loading history, functional use, and structural integrity, even in segments that do not directly contribute to force production during the sport-specific movement (HILKENS *et al.*, 2023; FLORVÅG *et al.*, 2025).

In handbike parathletes, greater lower-limb bone mineral density may be associated with improved postural stability and more efficient positioning on the equipment. It may also enhance the capacity to withstand loads transmitted throughout the body during cyclic propulsion, particularly during accelerations, terrain variations, and speed maintenance (KRAAIJENBRINK *et al.*, 2020; STEPHENSON *et al.*, 2020). Although direct evidence remains scarce, studies in paracycling and rehabilitation contexts suggest that structural characteristics of the lower limbs may indirectly influence mechanical efficiency and the overall energy cost of movement (STEPHENSON *et al.*, 2020; HILKENS *et al.*, 2023; FLORVÅG *et al.*, 2025). Therefore, the observed association should be interpreted as indicative of a potential indirect functional role of bone mineral density in handbike competitive performance, reinforcing the need for future studies with larger samples and sport-specific designs.

4.4 VARIABLES WITHOUT SIGNIFICANT ASSOCIATION

In the present study, no significant associations were observed between competitive performance and isometric strength, dynamic strength, or relative power variables. The absence of these associations may be related to the specificity of the sport-specific movement, as general strength tests do not always accurately reflect the technical and neuromuscular demands imposed by the analyzed modalities. Although widely used in sports and clinical settings, general strength assessments tend to evaluate isolated capacities and may show limited sensitivity in discriminating competitive performance levels among high-performance athletes, particularly in sports in which technical execution, motor control, and neuromuscular efficiency play central roles.

4.5 LIMITATIONS AND SUGGESTIONS FOR FUTURE STUDIES

The present study has some limitations that should be considered when interpreting the results. The small sample size, characteristic of pilot studies, limits the generalization of the findings and restricts the possibility of conducting more robust analyses by functional class or sex, a condition

inherent to the specificity of the population evaluated, composed of high-performance parathletes from modalities with a naturally limited number of competitive participants.

The functional heterogeneity of the participants, inherent to the Paralympic sport context, as well as the specific characteristics of each modality, may also have influenced the results. Despite these limitations, the study provides relevant information regarding potential functional markers associated with competitive performance. Therefore, future studies with larger samples, longitudinal designs, and analyses stratified by functional class are necessary to further understand these relationships and to confirm the findings observed.

4.6 PRACTICAL IMPLICATIONS

From a practical perspective, the assessment of upper-limb anaerobic power represents a relevant tool in the context of Paralympic sport, as this capacity is directly related to force production and maintenance in modalities that predominantly rely on upper-limb actions. Understanding this physical profile allows coaches and professionals working with parathletes to better comprehend the demands imposed by the sport-specific movement, assisting in the identification of performance-determining capacities, monitoring athletic development, and supporting decision-making throughout the training process.

Furthermore, these assessments may contribute to the systematic monitoring of athletes' progress, supporting more individualized and effective training load prescriptions, as well as informing strategies for athlete selection, classification considerations, and training progression within high-performance programs designed for athletes with disabilities.

Additionally, the findings related to body composition and structural characteristics highlight the importance of integrated biodynamic assessments that consider not only maximal strength but also aspects such as body mass distribution, postural stability, and the athletes' functional history. These elements may provide valuable support for decision-making in training planning, performance monitoring, and injury or overload prevention strategies.

5 CONCLUSIONS

It can be concluded that biodynamic variables related to upper-limb anaerobic power and body composition were associated with competitive performance in Handbike and Paralympic Powerlifting parathletes. Mean power emerged as a potential functional marker of performance, while modality-specific characteristics—such as time of practice in Paralympic Powerlifting and lower-limb bone mineral density in Handbike—demonstrated relevant associations when analyses were stratified by sport.

These findings contribute meaningfully to the understanding of physical factors associated with performance in Paralympic sport and provide practical support for individualized planning and applied strategies within functional assessment and training programs aimed at optimizing competitive performance.

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