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Muscle power performance in parabadminton athletes: Influence of classification, impairment type, and anthropometric factors

Saulo FM Oliveira[1], José Igor V Oliveira[2], João Fillype VV Alves[1], Thiago Lourenço[3], Marcelo C Haiachi[4], and Hanno Felder[5]

Abstract

This study compared muscle power indicators among Parabadminton athletes and identified the contributions of anthropometric factors and types of impairment. Seventy-four athletes, comprising 47 in the ST group (STANDING-ST, SL3, SL4, SU5, and SH6) and 27 in the WH group (WHEELCHAIR-WH, WH1 and WH2), underwent muscle power tests. The ST group performed three countermovement jumps (CMJ), measuring maximum height (CMJMax, cm), percentage of maximum height (%CMJMax), power (PO, W), and reactivity index (RI). The WH group performed three medicine ball throws, with the best throw (BEST, m), percentage of the best throw (%DIFMax), absolute power (PO, W), and relative power (PO, W/kg) measured. MANCOVA comparison tests were conducted ($p < 0.05$). For PO (W), SU5 athletes exhibited higher values than SL3 and SH6 athletes (*1920 W vs. 1020 W* and *814 W*), and SL4 athletes showed higher values than SL3 and SH6 athletes (*1604 W vs. 1020 W* and *814 W*). In the WH group, BEST and PO (W) were superior for the WH2 class (*5.27 m vs. 6.40 m;* and *10.5 W vs. 12.8 W*). In the ST group, type of impairment and body mass index significantly influenced CMJMax ($F = 522.837$, $p = 0.028$) and RI ($F = 561.829$, $p = 0.023$), while in the WH group, the classification influenced BEST ($F = 8.410$, $p = 0.008$) and PO (W) ($F = 96.181$, $p = 0.005$), with height affecting BEST ($F = 19.154$, $p < 0.001$) and PO (W) ($F = 191.539$, $p < 0.001$). It can be concluded that type of impairment, body mass index, and height influence the best indicators of muscle power regardless of the classes analyzed.

Keywords

People with disabilities, paralympic sport, para sport, para badminton, racket sport

Introduction

Badminton is a racket sport enjoyed by individuals of all genders, ages, and backgrounds. While its exact origins remain uncertain, it is believed to have originated in China and India before further development occurred in Badminton, England, which ultimately lent its name to the sport. Since being included in the Olympic Games in Barcelona in 1992, badminton has continued to grow in popularity.[1] Over the past two decades, there has been a significant rise in the participation of individuals with impairments in sports, leading to badminton's inclusion in the Summer Paralympics for the first time at the Tokyo 2020 Games, held in 2021.[2]

In its inaugural appearance at the Paralympics, Parabadminton (PBd) featured 90 athletes from various countries, as reported by the International Paralympic Committee (IPC). These athletes are categorized into six sports classes: WH1, WH2, SL3, SL4, SU5, and SH6. The WH1 and WH2 classifications are designated for para-

[1]Movement, Rehabilitation and Sport Study Group, Department of Physical Education and Sports Science, Federal University of Pernambuco, Recife, Brazil
[2]Applied Kinesiology Laboratory, School of Physical Education, Universidade Estadual de Campinas, Campinas, Brazil
[3]Brazilian Paralympic Committee, São Paulo, Brazil
[4]Department of Physical Education, Federal University of Sergipe, Aracaju, Brazil
[5]Olympic Training Center Rhineland Palatinate/Saarland, Hermann Neuberger Sportschule, Saarbrücken, Germany

Corresponding author:
José Igor V Oliveira, Applied Kinesiology Laboratory, School of Physical Education, Universidade Estadual de Campinas, Av. Érico Veríssimo, 701 - Geraldo, Campinas – Brazil/SP, 13083-851. Phone: +55 19 3521-6606.
Email: igorvasconcelos200@hotmail.com

athletes who compete in wheelchairs due to conditions such as spinal cord injury, spina bifida, or congenital malformation, and they play on a reduced court (4.72 m×3.05 m). Athletes in the SL3 category, who have severe lower limb limitations, also compete on a reduced court, but they play while standing. In contrast, athletes in the SL4 (moderate lower limb limitations), SU5 (upper limb limitations), and SH6 (individuals with short stature) categories utilize the full court (13.40 m×3.05 m) during competition.[3] These differences in classification, court size, and movement requirements create distinct physiological demands across categories, influencing factors such as endurance, agility, and strength.[4]

As an acyclic sport, PBd presents varying demands during gameplay, alternating between high-intensity activities and periods of active and passive recovery.[4–6] Despite this diversity in energy expenditure, the most crucial actions within a match typically occur during moments of heightened intensity. During these instances, athletes require significant muscle power in both their upper and lower limbs to execute strikes or move with accelerated speed.[7,8] It is recognized that there are significant associations between aspects of body composition and muscle power among conventional badminton athletes.[9] However, the extent of these associations and dependencies remains largely unexplored in the context of PBd, particularly considering the diverse classifications and the range of potentially eligible impairments.

It is worth noting that detailed knowledge of parameters, such as power, that can better predict sports performance in PBd is scarcely evidenced in the literature. Understanding these variables through physical tests is crucial for enhancing training methods and strategies for PBd athletes and for discriminating between classifications based on scientific evidence.[4,6,10,11] Therefore, there is a clear need to investigate and delve into the factors that can influence and more accurately determine the impact of impairment on the performance of PBd athletes. In this regard, the present research aims to: (a) compare the muscle power indicators of PBd athletes belonging to different classes; and (b) identify the contributions of anthropometric factors and types of impairment to the parameters of muscle power among athletes.

Materials and methods

Study design

The para-athletes were divided into two groups: STs (comprising STANDING-ST, SL3, SL4, SU5, and SH6) and WHs (including WHEELCHAIR-WH, WH1, and WH2). The ST group underwent three countermovement jumps (CMJ), during which maximum height (CMJMax, cm), percentage of maximum height (%CMJMax), power (PO, W), and reactivity index (RI) were measured. The WH group performed three medicine ball throws, with the best throw (BEST, m), percentage of the best throw (%DIFMax), absolute power (PO, W), and relative power (PO, W/kg) recorded. All research activities were conducted during official tournaments (all assessments were performed before each match) to ensure the participation of athletes with ample experience in the sport and optimal physical condition. The evaluations took place in a sports gym, which served as the venue for the championships, and were supervised by the study authors. All assessments were conducted in one day, prior to any physical exertion, ensuring that the athletes were well-rested and not fatigued.

Participants

Seventy-four PBd athletes from American and Asian countries participated in the evaluation, distributed as follows: WH1 = 12, WH2 = 15, SL3 = 8, SL4 = 13, SU5 = 13, and SH6 = 13. The athletes were divided into two groups: 47 STs (Age: 28.98 ± 10.38 years; Experience time: 73.1 ± 72.19 months; Body mass: 62.66 ± 13.66 kg; Height: 1.70 ± 9.33 m; Body Mass Index: 24.97 ± 6.21 kg.m^2) and 27 WHs (Age: 34.95 ± 8.27 years; Experience time: 43.16 ± 34.89 months; Body mass: 65.50 ± 13.06 kg; Height: 1.63 ± 0.16 m; Body Mass Index: 24.91 ± 6.54 kg.m^2). Athletes who volunteered to participate in the procedures were recruited during official national and international championships recognized by the Badminton World Federation and organized and administered by the Brazilian Badminton Confederation. To be eligible for the study, athletes were required to have an official classification and have previously participated in at least one official championship (national or international) in Para-sport. All procedures outlined in this study were approved by the Ethics Committee in Research of Human Subjects at the University of the first author (protocol number 5.982.980) (written informed consent). The entire study followed the standards indicated by the Declaration of Helsinki.

Procedures

Anthropometric and impairments characteristics. The anthropometric information of each athlete was gathered using a form developed by the researchers, which included anthropometric data, sporting experience, and classification. An experienced researcher (i.e., International Certification in Anthropometry – ISAK) conducted all anthropometric measurements, adhering to international and specific standards for individuals with impairments.[12] To characterize the morphological profile of the athletes, the sum of five skinfold measurements (triceps, biceps, suprailiac, axillary, and abdominal) were utilized, considering accessibility to anatomical points for collection. Given the absence of specific protocols for assessing body fat in individuals with impairments, standardization of body

adiposity was achieved using the sum of skinfold measurements evaluated in millimeters. Additionally, the circumference of the right arm (or the functional arm in cases of morphological limitations on the right side) was measured to determine the arm muscle area (AMA) using the following equation[13]: $AMA = (AC - \pi \times TS) \times 2 / 4 \times \pi$, where AC represents the circumference of the corrected arm, and TS denotes the measurement of the corrected triceps skinfold. Alongside the AMA, isolated AC was employed as a criterion for controlling comparisons in multivariate analyses.

Measurement of the strength-power of the lower limbs. This protocol was exclusively conducted for athletes in the SL3, SL4, SU5, and SH6 classes. The testing session commenced with a standardized warm-up procedure, comprising 5 min of running at an individual pace followed by 10 min of calisthenic and dynamic stretching exercises. Subsequently, participants were invited to undergo the countermovement jump (CMJ) test to assess lower limb power through vertical jump height. Throughout the CMJ test, participants wore an inertial acceleration and speed unit (BIOBIT, Kinetec, Brazil), securely fastened around the waist with a comfortable elastic strap.[14]

All athletes were instructed to place their hands on their hips during the jump to minimize the influence of arm swing. The jump began with participants executing a maximal vertical push (stretching-shortening cycle) while bending their knees to approximately 90 degrees. Upon reaching the apex of the jump, participants were instructed to maintain a straight body posture and fully extend their knees during descent.[15] Any jumps executed with incorrect technique or lacking data recording by the inertial unit were repeated. Each volunteer was allowed to perform at least two repetitions using the appropriate technique to perform the jump. A one-minute rest interval was permitted between consecutive jump attempts to mitigate the effects of fatigue. The best performance measurements from three attempts were directly recorded using the inertial sensor software. The following variables were calculated: (a) maximum jump height (CMJMax, cm); (b) lower limb power (PO, W), calculated by multiplying the maximum height attained by the athletes' body mass; (c) percentage difference between attempts (%CMJMax), calculated using the equation: $DIF\% = (worst\ jump\ /\ best\ Jump) \times 100$; and (d) the reactive force index (RI) using the mean difference of the contact time between the jump repetitions, by means of the equation $RI = Jump\ Height\ /\ Contact\ Time$, by accelerometer (BIOBIT, Brazil). It is worth noting that the variable has already been frequently used to monitor vertical jump indicators.[16,17]

Measurement of the strength-power of the upper limbs. For this assessment, the Medicine Ball Throwing Test (MBT) was employed, exclusively for athletes in the WH1 and WH2 classes. This decision was made following recommendations from previous studies that utilized this test with wheelchair athletes.[18,19] Before starting the test, the athletes performed a two-minute dynamic warm-up that included stretching and upper limb mobility. The participant was seated in their own sports wheelchair and given a 1 kg medicine ball for familiarization purposes (to minimize the impact of wheelchair height on test results, participants were positioned in a standardized manner, ensuring uniform seat height and using chairs with similar measurements). Following this, they were instructed to perform three consecutive throws, with intervals of 30 s between each throw, using a 2 kg medicine ball. The throw involved a rapid extension of the elbow, pushing the ball from the center of the chest (sternum) with maximum voluntary power to achieve the highest trajectory and reach a specific distance, which was measured by the evaluator.

The distance covered by the ball, measured in meters, was recorded using a tape measure extended from the position where the athlete was seated. In addition to recording the longest distance achieved (BEST), the following calculations were made: (a) The percentage difference between attempts (first and second longest distance) (%DIFMax), calculated using the equation: $DIF\% = (worst\ throw\ /\ best\ throw) \times 100$; (b) the absolute power (PO, Watts), calculated by multiplying the weight of the ball by the distance reached; and (c) the relative power (PO, watts/kg), determined by dividing the absolute power by the athlete's body mass.

Statistical analyses

The normality of the data was assessed using the Shapiro-Wilk test. Two groups, Standing and Wheelchair, along with their respective subgroups (Standing: SL3, SL4, SU5, and SH6; Wheelchair: WH1 and WH2), were considered for the analyses. For the Standing group, as normality assumptions were violated, the sports classes were compared using a Kruskal-Wallis test, followed by post-hoc Dwass-Steel-Critchlow-Fligner (DSCF) analysis. In the Wheelchair group, the WH1 and WH2 subgroups were compared using an unpaired T-test. Subsequently, to assess the influence of anthropometric characteristics on muscle power levels among classifications, MANCOVA analyses were conducted for each subgroup of athletes. The covariates considered in the analysis included age (years), body mass (kg), height (m), body mass index (kg/m^2), arm muscle area (cm^2), corrected arm circumference (cm), sum of skinfolds (mm), practical experience time (months), gender (male and female), and type of impairment (other unspecified impairments according to criteria of the International Paralympic Committee designated as "*les autres*"). The classification remained as an independent variable, while the muscle power indicators evaluated by both protocols (MBT and CMJ) served as dependent

variables. All analyses were conducted using the JAMOVI software (version 2.3.18.0, USA), with a significance level set at 5% ($p < 0.05$).

Results

Table 1 presents the demographic and anthropometric data (mean and standard deviation) of the entire sample of athletes evaluated, considering both analysis groups (Standing and Wheelchair).

Comparisons between athletes of classes within the groups evaluated

Table 2 shows the muscle power indicators for both groups, considering each class and the variables relevant to the tests used.

When comparing these indicators for the Wheelchair group, statistically significant differences were observed about the "best throw" and "absolute power". Specifically, the values for the WH2 class were higher compared to WH1 (*5.40 m vs. 5.27 m* for the best throw, and *12.8 W vs. 10.8 W* for absolute power; Figure 1).

In the Standing group, significant differences were observed in maximum height, power, and reactivity index. For maximum height, the SU5 group exhibited higher values compared to the SL3 and SH6 groups (*29.2 cm vs. 16.5 cm* and *16.0 cm*, respectively). In terms of power, the SU5 athletes demonstrated higher values compared to the SL3 and SH6 classes (*1920 W vs. 1020 W* and *814 W*, respectively). Similarly, the SL4 athletes had higher power values than the SL3 and SH6 classes (*1604 W vs. 1020 W* and *814 W*, respectively). Regarding the reactivity index, significantly higher values were observed in the SU5 and SL4 classes compared to the SL3 class (*0.522* and *0.519 vs. 0.324*, respectively) (Figure 2).

Table 1. Demographic and anthropometric characteristics of the sample were evaluated (N = 74).

Characteristics	Mean ± Standard deviation	
	Standing group (N = 47)	Wheelchair group (N = 27)
Age (years)	28.98 ± 10.38	34.95 ± 8.27
Gender		
Male	31	19
Female	16	08
Sport classes		
WH1	–	12
WH2	–	15
SL3	08	–
SL4	13	–
SU5	13	–
SH6	13	–
Type of eligible impairment		
Spinal cord injury	–	17
Poliomyelitis	02	04
Spina bifida	–	01
Amputations	05	–
Congenital malformation	08	–
Short stature	13	–
Cerebral palsy and similar sequelae	10	01
Les autres	09	04
Time of experience (months)	73.1 ± 72.19	43.16 ± 34.89
Body mass (kg)	62.66 ± 13.66	65.50 ± 13.06
Height (m)	1.70 ± 9.33	1.63 ± 13.16
Body Mass Index (kg.m^2)	24.97 ± 6.21	24.91 ± 6.54
The Sum of 5 skinfolds (mm)	103.68 ± 43.30	94.85 ± 41.66
Arm muscle area (cm^2)	4.55 ± 0.53	4.84 ± 0.75
Arm circumference corrected (cm)	28.95 ± 3.38	30.73 ± 4.72

Comparisons between classifications in the presence of covariates (MANCOVA analyses)

In the Standing group, among the variables included in the multivariate analysis model, the type of impairment influenced CMJMax ($F = 522.837$, $p = 0.028$), and body mass index was associated with the reactivity index ($F = 561.829$, $p = 0.023$). Additionally, only the classification was found to be significant in influencing the reactivity index ($F = 372.143$; $p = 0.019$) (Table 3).

In the Wheelchair group, the classification exhibited significant influences on the best throw ($F = 8.410$; $p = 0.008$) and absolute power ($F = 96.181$; $p = 0.005$). Furthermore, height also showed significance with the best throw ($F = 19.154$; $p < 0.001$) and absolute power ($F = 191.539$; $p < 0.001$) (Table 3).

Discussion

The objectives of this investigation were (a) to compare the muscle power indicators of PBd athletes belonging to different classes and (b) to identify the contributions of anthropometric factors and types of impairment on the parameters of muscle power of athletes. In the Wheelchair group, differences were observed between classes WH1 and WH2 only for the BEST and PO(W) indicators (Figure 1). Conversely, in the Standing group, significant differences were found for CMJMax between athletes of classes SU5, SH6, and SL3, for PO(W) among all classes, and for RI among athletes of classes SU5, SL4, and SL3 (Figure 2). Moreover, the MANCOVA analysis revealed that in the Standing group, besides classification, the type of impairment and body mass index significantly influenced CMJMax and RI, respectively (Table 3). For the Wheelchair group, it was observed that classification and height significantly influenced BEST and PO(W), respectively (Table 3).

Table 2. Muscle power indicators according to classes.

	Standing Groups (N = 47)			
Variables (CMJ)	SL3	SL4	SU5	SH6
CMJMax (cm)	16.6 ± 5.55	22.8 ± 6.71	29.2 ± 6.45	16.0 ± 5.76
%CMJMax	87.8 ± 7.16	91.2 ± 5.57	91.6 ± 5.42	81.0 ± 22.3
PO(W)	1020 ± 394	1604 ± 371	1920 ± 509	814 ± 340
RI(score)	0.324 ± 0.140	0.519 ± 0.138	0.522 ± 0.143	0.484 ± 0.176
		Wheelchair Groups (N = 27)		
Variables (MBT)		WH1		WH2
Distance throw (m)		5.27 ± 1.08		6.40 ± 1.58
%DIFMax		94.6 ± 4.33		94.0 ± 4.62
PO(W)		10.5 ± 2.15		12.8 ± 3.17
PO(W/kg)		0.176 ± 0.02		0.189 ± 0.1

Notes: CMJ = Countermovement Jump; CMJMax = maximum jump height; %CMJMax = percentage of the difference between attempts; RI = reactivity index; MBT = Medicine Ball Throw; %DIFMax = percentage of the difference between attempts; PO = absolute power; PO (W/kg) = relative power.

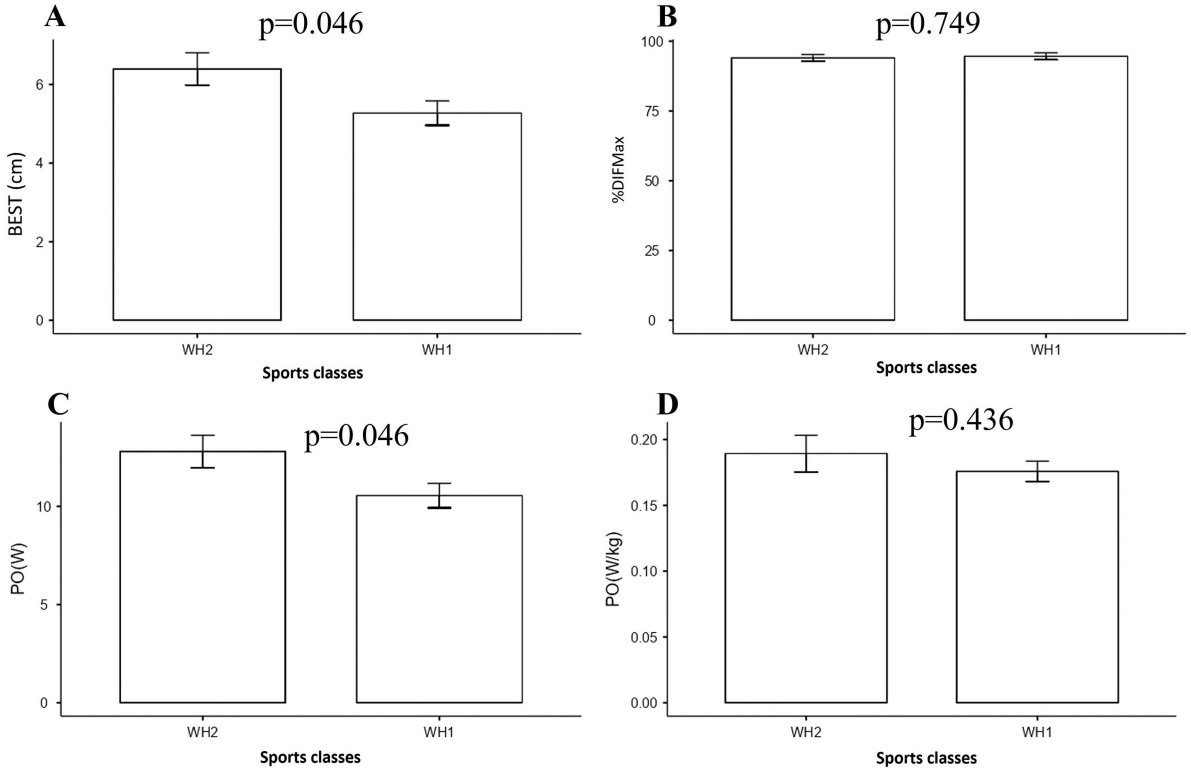

Figure 1. Comparisons between upper limb muscle power indicators among athletes in wheelchair sports classes (WH1 and WH2).

For functional class reasons, specifically considering the type of impairment, the decision was made to divide the sample into two distinct groups: Standing and Wheelchair. This division was based on the understanding that muscle power indicators would differ according to the needs of PBd athletes themselves. Upon observing the Standing groups, it was noted that athletes in the SU5 class consistently exhibited superior muscle power indicators compared to para-athletes in other sports classes (Figure 2), particularly in terms of maximum height, PO, and RI. This finding can be explained from a functional perspective: the SU5 class (29.2 ± 6.45 cm jump height; 1920 ± 509 jump power), designated for para-athletes with upper limb impairments, often exhibits movements, techniques, and physical capabilities similar to those of conventional badminton athletes.[7,20] While this

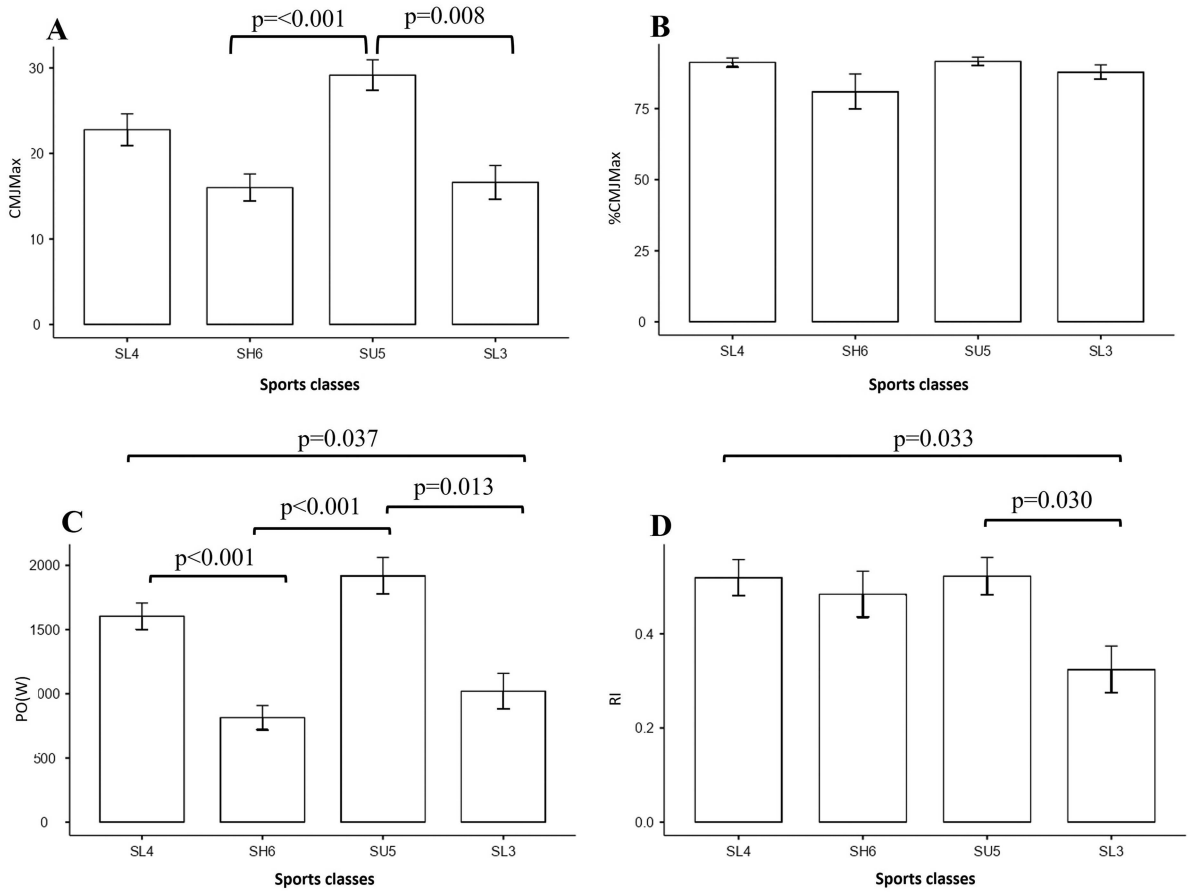

Figure 2. Comparisons between lower limb muscle power indicators among athletes in standing sports classes (SL3, SL4, SU5, and SH6).

observation is often evident in practice, this study represents the first reported investigation to systematically evaluate such differences between classifications in terms of muscle power. When comparing para-athletes with minimal deficiencies to those with functional deficits in areas such as range of motion, balance, or muscle mass, it's natural for SU5 athletes to possess certain advantages.

Considering power values alone, athletes in the SL4 and SU5 classes exhibit higher values compared to athletes in the SL3 and SH6 classes. This difference can be attributed to the significant reduction in body mass among athletes with short stature (class SH6) and severe mobility impairments (class SL3), as power (PO) is directly influenced by body mass. Additionally, anthropometric factors contribute to the lower PO values observed in both classes. Para-athletes with short stature (class SH6) experience mechanical disadvantages due to smaller levers in the lower limbs, which primarily account for the reduction in muscle power. Conversely, athletes in the SL3 class commonly face limitations in motor control, balance, and coordination, resulting in lower PO values in this group.[5]

It is noteworthy that in the studied sample, there are many para-athletes with cerebral palsy (CP) distributed between the SL4 and SL3 classes, with even more athletes with CP in the SL4 class than in the SL3 class. Consequently, predicting the physical fitness prognosis of para-athletes with CP is exceedingly challenging, particularly because the eligibility criterion for the SL3 class is related to the reduction of their ability to move across the full court. The literature has emphasized the importance of monitoring the reduction in physical capacities of para-athletes with CP in various sports.[21–23] It appears that for PBd, the vertical jump can serve as a robust discriminator for para-athletes with CP (and, consequently, for other eligible impairments included in PBd), especially for those with significant coordination impairments. Moreover, athletes classified in the SL3 class due to lower mobility may greatly benefit from neuromuscular training to enhance their jumping ability.

It was also observed that in the Wheelchair group, there were higher values in class WH2 compared to class WH1 (Figure 1; Panels A, C, and D). Typically, para-athletes with more severe spinal cord injuries and limited trunk action (class WH1) tend to exhibit lower indicators of anaerobic, aerobic, and muscle power performance,[24,25] a trend corroborated by the findings of this investigation. Greater motor control of the trunk muscles may enhance forward-reaching ability, potentially contributing to better

Table 3. Multiple comparisons of muscle power indicators for the group of athletes standing and wheelchair, according to the covariates selected by multivariate analysis (MANCOVA).

	Standing Group (N = 47)		
Covariables	Variables	F	P
Classification	CMJMax	1.289.99	**<0.001**
	%CMJMax	174.81	0.173
	PO(W)	1.876.37	**<0.001**
	RI	372.14	**0.019**
Impairment type	CMJMax	522.83	**0.028**
	%CMJMax	0.01	0.898
	PO(W)	0.94	0.338
	RI	0.45	0.503
Body Mass Index	CMJMax	242.22	0.128
	%CMJMax	0.12	0.728
	PO(W)	139.01	0.246
	RI	561.82	**0.023**
	Wheelchair Group (N = 27)		
Covariables	Variables	F	p
Classification	BEST	8.41	**0.008**
	PO(W/kg)	0.68	0.418
	PO(W)	96.18	**0.005**
Impairment type	BEST	5.62	**0.027**
	PO(W/kg)	3.20	0.087
	PO(W)	0.02	0.885
Body Mass Index	BEST	19.15	**<0.001**
	PO(W/kg)	0.89	0.354
	PO(W)	191.53	**<0.001**

Notes: CMJ = Countermovement Jump; CMJMax = maximum jump height; %CMJMax = percentage of the difference between attempts; RI = reactivity index; PO(W) = absolute power; PO (W/kg) = relative power; BEST = best throw.

performance in WH2 athletes compared to WH1. It is noteworthy that, although the maximum values (best medicine ball throw) were higher in WH2 athletes, there were no significant differences ($p > 0.05$) observed when considering the relative values (Watts/kg and %DIFMax). This suggests that in submaximal activities or when athletes effectively apply their technical characteristics (e.g., body function and ergonomics), a degree of performance compensation may occur between WH1 and WH2 athletes, resulting in similar abilities in certain aspects.

The MANCOVA results revealed that certain covariates significantly influence comparisons and some indicators of muscle power (Table 3). Specifically, the type of impairment remained a significant factor influencing the maximum power indicators in both analysis groups, Wheelchair and Standing (best throw and maximum jump height). Undoubtedly, the maximum capacity to exert power is greatly influenced by the type of impairment, particularly when considering borderline sports classes, where there may be some uncertainty in classifying a particular athlete (WH1/WH2 and SL3/SL4). These differences are believed to be particularly evident in severe impairment, such as spinal cord injuries and cerebral palsy,[26,27] especially when considering neuromuscular development (i.e., congenital or childhood-acquired deficiencies).[28]

In the analysis of the Standing group, it was observed that body mass index significantly influences the differences between classes for RI (Table 3). Apart from the ability to develop strength in very short time intervals, a greater body volume can potentially hurt this capacity, as it may complicate weight transfer (strength) in jump activities, which are characteristic of PBd. Therefore, considering that certain types of impairment may predispose individuals to accumulate body fat or even lead to a reduction in skeletal muscle mass,[22,29] it is plausible that these athletes may encounter challenges in maintaining optimal levels of body composition, constrained by their specific conditions of impairment, despite being in a typical locomotive position. From a neuromuscular perspective, it is important to highlight that some athletes encounter specific challenges in executing the jumping motion with proper motor control, particularly when the movement is performed repeatedly. Athletes with cerebral palsy competing in "standing" classes often experience impairments due to hypertonia, ataxia, or athetosis, which can significantly impact neuromuscular performance.[30]

Conversely, PO was influenced by height in the Wheelchair group (Table 3). The final distance reached in the throwing gesture, which limits the natural action of hitting the shuttlecock, appears to be influenced by the height of the throw. This relationship has been demonstrated in previous studies.[31,32] Apart from the technique employed by the athlete, their functionality and level of adaptation also play a role in determining the best performance achieved. Moreover, anthropometric factors can confer certain competitive advantages in sports characterized by overhead actions. This implies that even WH1 athletes could potentially benefit from advantages in terms of PO when they fully utilize their wheelchairs and adapt to their seated position to achieve the optimal range of motion.[8,33]

Despite the findings identified in the present study, it is important to highlight several limitations. Firstly, the slightly reduced number of athletes in the subgroups of analysis may have compromised comparisons and increased the heterogeneity of the sample. Secondly, the imbalance in terms of types of impairment generally exacerbates this heterogeneity. European para-athletes were also not included in the evaluation, as they were unavailable for assessment. However, these limitations do not negate the conclusions drawn from our results. This observational study gathered a substantial sample of athletes from various countries, each with significant experience in PBd. Ultimately, this investigation clarifies the differences between classifications, providing valuable insights for coaches, sports scientists, and PBd stakeholders. These

insights can aid in developing more precise criteria for athlete monitoring and evaluation, both for classification purposes and training optimization. For classification, adding specific physical tests could improve the accuracy of athlete categorization, ensuring fairer competition by better distinguishing functional profiles. In terms of training load management, understanding each classification's specific muscle power demands allows for customized training interventions, helping to prevent injuries, optimize performance, and enhance long-term athlete development. These findings emphasize the need for evidence-based approaches in both classification and training methodologies, reinforcing the practical significance of this study for PBd.

Conclusions

These findings lead to several practical considerations: (a) when prescribing training based on muscle power, athletes in the SU5 class could be subjected to training stimuli that are more akin to those used for conventional badminton athletes; (b) athletes with greater trunk control can be encouraged to engage in higher-intensity explosive strength training compared to those with lower trunk control; (c) coaches and athletes competing in the Standing classes should take note of indicators of body composition and body mass, as these factors can influence jump technique and, consequently, overall performance; and (d) the type of impairment remains a crucial criterion for aligning strategies of classification and muscle power training for PBd athletes competing in wheelchairs.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Ethical considerations

All procedures outlined in this study were approved by the Ethics Committee in Research of Human Subjects at the University of the first author (protocol number 5.982.980) (written informed consent). The entire study followed the standards indicated by the Declaration of Helsinki.

Consent to participate

Informed consent to participate in the study was written (i.e., document) and verbal.

Consent for publication

Not applicable.

ORCID iDs

Saulo FM Oliveira https://orcid.org/0000-0002-4402-1984
José Igor V Oliveira https://orcid.org/0000-0002-0034-9638
Thiago Lourenço https://orcid.org/0000-0003-1518-9021 GQ6

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