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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Physiological and metabolic responses of Parabadminton athletes to field simulated effort

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ABSTRACT

BACKGROUND: Due to the increase in the number of Parabadminton (PBd) athletes and the lack of scientific knowledge of the sport, it is important to evaluate performance variables in different game stimuli. Thus, this study sought to examine the physiological and metabolic responses in a simulated effort protocol in PBd athletes.

METHODS: Forty-seven volunteers (WH1=7; WH2=9; SL3=8; SL4=9; SU5=6; SH6=8) performed a simulated effort protocol, consisting of 2 blocks of activities (1st change of direction + 1st simulated effort; 2nd change of direction + 2nd simulated effort). Peak and average oxygen consumption (VO_2peak and VO_2avg), peak, percentage, and average heart rate (HRmax, %HRmax, and HRavg), percentage of carbohydrates and lipids contributions (%CARB and %FAT), and average and total energy expenditure (EEavg and EEtotal) were evaluated. The data was compared between protocol stages, functional classes (FCs), and court size. It was adopted P<0.05.

RESULTS: Differences were found between the stages of the protocol in VO_2peak (P=0.0008), VO_2avg (P=0.0004); HRmax (P<0.0001); %HRmax (P=0.0001), HRavg (P=0.0001), %CARB (P=0.0001), %FAT (P=0.0001), EEavg (P=0.0002), and EEtotal (P=0.008). Among FCs, SL4 athletes were superior to WH1 athletes for VO_2peak (P=0.075), VO_2avg (P=0.022), EEavg (P=0.011), and EEtotal (P=0.022). Athletes who completed protocol in the full court were greater than half court for VO_2peak (P<0.001), VO_2avg (P<0.001), %HRmax (P=0.032), HRavg (P=0.018), %CARB (P=0.022), %FAT (P=0.022), and EEavg (P=0.016).

CONCLUSIONS: PBd athletes belonging to higher FCs (4, 5, and 6) and who cover greater distances on the court exhibit physiological and metabolic responses under greater influence of the type of disability.

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KEY WORDS: Para-athletes; Sports; Oxygen consumption; Heart rate; Energy metabolism.

Paralympic sports have gained a lot of evidence in the last 30 years, with considerable evolution in terms of sports performance with increased indicators in terms of technical skills and physical conditioning.[1] In this way, paralympic athletes have demanded greater effort in terms of training and assessment, in addition to the clear need to maintain excellent performance levels to continue with a competitive advantage over their opponents.[2, 3] For this reason, sports scientists have been increasingly concerned with deepening biological and technological knowledge about the demands of the actual sports, considering athletes' and modalities' specificities, for example in Parabadminton (PBd). Recently, PBd made its Paralympic debut in Japan (2020+1) (www.paralympic.org), with athletes with multiple motor disabilities being eligible in up to 6 different functional classes (FC). FC is divided into wheelchair users, motor impairment of lower limbs, motor impairment of upper limbs, and dwarfism. These FCs are clustered in

two main groups athletes with less mobility (WH1, WH2, and SL3) and less impairment (SL4, SU5, and SH6).[4] Despite the FCs, as PBd is a recent sport in the Paralympic scenario, so far, no studies have been developed to compare them. The only study available with a PBd athlete (class SL3) carried out showed a moderate correlation (*r*=0.62) between the maximal oxygen consumption (VO_2peak) achieved in the peak test and the oxygen consumption (VO_2) displayed in a simulated training session.[5] Similar to the Olympic sport, it is known that PBd is an intermittent sport, with mixed efforts in terms of metabolic demand (aerobic and anaerobic).[6] These demands are interspersed with explosive efforts, usually related to decisive moments in games.[7] In this sense, studies with professional badminton athletes in simulated experiments showed that VO_2, heart rate (HR), and blood lactate concentrations during badminton matches vary around 39.6 $ml \cdot kg^{-1} \cdot min^{-1}$, 169 bpm, and 1.9 $mmol \cdot L^{-1}$, respectively.[8] However, no studies were designed to investigate it in PBd. These findings suggest that the average intensity of the badminton game and the considerable variability of several physiological parameters demonstrate the importance of anaerobic metabolism and aerobic energy production in competitive badminton.[9] Most investigations are carried out in a laboratory environment, and conducted through incremental physical effort protocols which don't provide specific information about the different physiological and metabolic responses to the specific effort of the PBd.[10, 11] In addition, it is necessary to understand how these responses occur into different FCs, considering that the type of disability can also decisively influence the responses found. This information may help athletes and coaches determine the most effective and adequate strategies to stimulate these capacities during the training process. Thus, the objectives of the present investigation were a) to examine the physiological and metabolic responses considering the phases of the simulated game-training protocol, the functional classes of the athletes, and the size of the court used for the performance; and b) to identify the influence of the type of disability in the various functional classes. Hypothesized that athletes from different FCs present different responses in terms of magnitude, and these responses may be modulated by the type of disability.

Material and methods

Research and sample

This investigation has a cross-sectional character, with an almost experimental design.[12] 47 athletes participated in the study (WH1=7; WH2=9; SL3=8; SL4=9; SU5=6; SH6=8) (age: 28.9±10.8; body mass: 62.9±15.4 kg). To participate in the study, the athlete should have an official FC and have previously participated in at least one official championship (*i.e.*, national, or international) of the sport. The athletes who volunteered to participate in the procedures were recruited during an official championship recognized by the Badminton World Federation (BWF), under administration and organization by the Brazilian Badminton Confederation. It was decided to carry out the research in an official tournament to bring together athletes with more experience in the modality and better physical conditions to participate in the research. Then, the time for participation in the experiment was scheduled with each coach and athlete, with the subsequent signing of the Informed Consent Form. The subjects were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study. All procedures in this study were approved by the Research Ethics Committee of the first author (N. 5.294.814).

Experimental approach

A simulated game-training session of the modality was developed to approach the real demand of the game, according to previous studies with conventional badminton athletes.[13, 14] The effort consisted of 2 identical blocks both composed of the same activities. Each block was composed of a moment of change of direction (COD) followed by a 5-minute rally.[5] The direction change task was performed consisting of movements performed at the 4 points of the court. The athlete was instructed to move as quickly as possible toward cones (40 cm high) placed at each corner of the court. For each diagonal movement, the athlete should touch the cone and return to the center point of the court. To bring the movement closer to reality, shuttlecocks were added to the top of each cone so that athletes could drop them with one touch. In total, each athlete performed 10 repetitions, with a 30-second interval between repetitions. For the rally, an experienced coach (level 1), a member of the research team, participated as a shuttlecock feeder. The rally was conducted in such a way as to keep the athlete always moving and considering the characteristics of the game for each functional class (Figure 1). For example, WH1 and WH2 class athletes who compete in wheelchairs were instructed to maintain their characteristic posterior and reverse motion. Throughout the rally, the athlete was allowed to perform any type of shot, except for a smash. The athlete was instructed to always return the shuttlecock

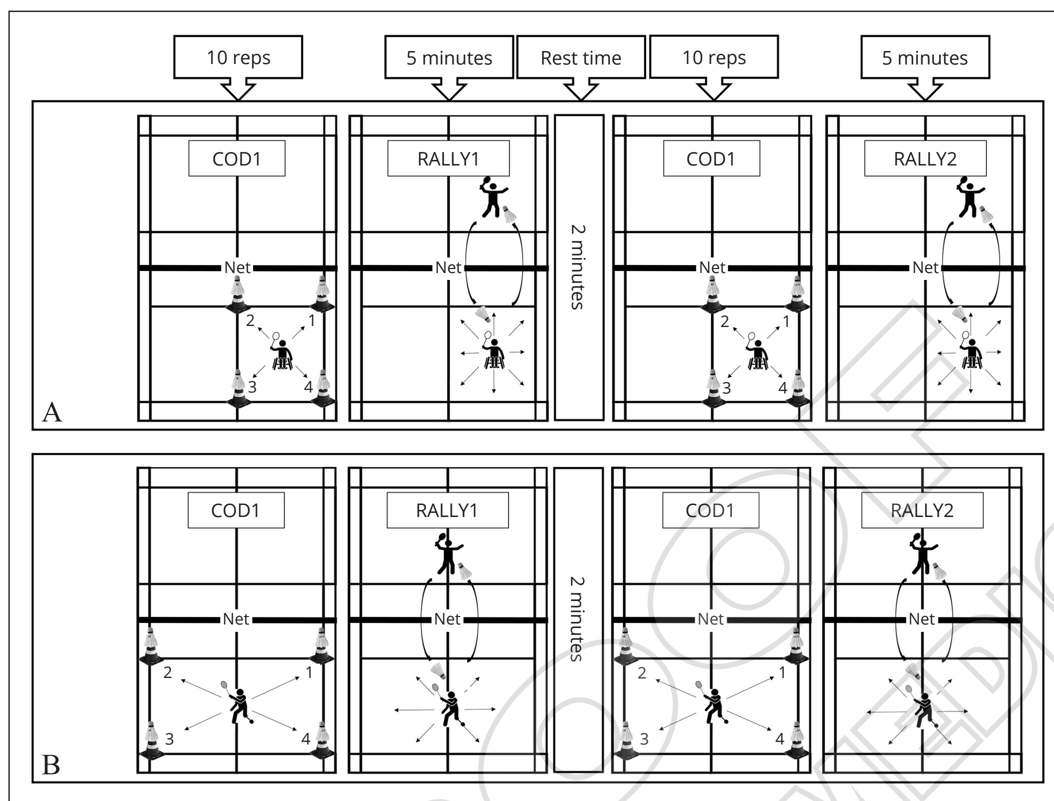

Figure 1.—Experimental protocol: A) data collection of athletes WH1, WH2 and SL3 (half court); and B) data collection of athletes SL4, SU5 and SH6 (full court). COD1 and COD2 (change of direction protocol); RALLY1 and RALLY2 (simulated rally controlled by experienced badminton trainer).

in a comfortable position for the coach. The coach was instructed always to return the shuttlecocks for the athlete to move around, considering a moderated level of difficulty on the perceived exertion scale (0-10 points).[15] Whenever there was a lack of control (fall) of the shuttlecock, another researcher quickly returned another shuttlecock so that the rally continued with as little break as possible. Between each block of activities (COD+RALLY), a rest period of 2 minutes was given. Every protocol is designed to especially emphasize modality-specific intermittent aerobic and anaerobic overload.[9] Because it was carried out during the competition, the athletes were instructed to participate in the experiment always fed (at least 2 hours before the test), and always with an interval of more than 1 hour after an official match. Athletes who had more than 2 games on the same day were instructed to participate at another time in the research.[16] Considering the differences between FCs that compete on the half court (WH1, WH2, and SL3), the dimensions of COD and rally were duly adopted. At the end of the entire protocol, the Borg scale was again presented to measure each athlete's perception of exertion. Figure 1 shows an illustration of the simulated effort protocol.

Procedures

Demographic data

Initially, the athletes were invited by the research team to the place where all the procedures would be performed. An official court in PBd was duly reserved for the experiment, with approval from the organization of the event. The demographic information of each athlete was collected using a form produced by the researchers themselves, containing anthropometric information, sports experience, and functional classification. All anthropometric measurements were performed by an experienced researcher and followed international and specific standards for people with disabilities.[17] The sum of 4 skinfolds (triceps, biceps, suprailiac, and abdominal) was used to characterize the morphological profile of the athletes due to the accessibility of the anatomical points for collection.[18]

Physiological and metabolic analysis

During the entire simulated protocol, heart rate (HR), oxygen consumption (VO_2), and carbon dioxide production (VCO_2) were monitored for a breath-by-breath strategy.

The HR was measured by a monitor via Bluetooth telemetry (Polar FT10; Polar Electro, Kempele, Finland), with a strap directly connected to the athlete's torso. The VO_2 and VCO_2 were collected by a portable system also *via* Bluetooth telemetry portable metabolic device (PNOE, Malden, MA, USA).[19] The unit runs on lithium batteries and weighs approximately 800g. The device consists of a single housing (120×110×45 mm, height, width, and length, respectively), attached to a shoulder strap and carried by the subject during physical exertion. Each athlete wore an appropriate mask and breathed through the hot film anemometer flow sensor. The VO_2 was measured using an indirect open-circuit calorimetry technique, assessing pulmonary gas exchange in the mouth and nose. Unit components include an electrochemical VO_2 analyzer and an infrared carbon dioxide analyzer. Energy expenditure was estimated using the indirect calorimetry technique, considering a metabolic equivalent in kcal for each liter of VO_2 consumed. The VO_2 and VCO_2 values were crossed to determine the respiratory quotient and subsequent energy production contribution derived from carbohydrates (%CARB) and fats (%FAT) during the exercise protocol. The recommendations of the equipment manufacturer were followed; therefore, it was considered that a respiratory exchange ratio of 0.75 indicated that fat was the predominant fuel source, a value of 1.0 was indicative that carbohydrates were the predominant source and a value between 0.75 and 1.0 suggested a mixture of fat and carbohydrates, with a higher proportion of carbohydrates.[20] After collecting the information, the percentage of each macronutrient for each step of the simulated effort was considered. We added this information to the text to make it clearer. Each stage of the protocol (COD1, RALLY1, COD2, and RALLY2) was analyzed separately. Derived variables for further analysis were the peak and average oxygen consumption (VO_2peak and VO_2avg), the peak, percentage, and average heart rate (HRmax, %HRmax, and HRavg), the %CARB; %FAT and the average and total energy expenditure for each stage (EEavg and EEtotal). The average and total values for the entire protocol were considered for later comparisons between athletes from different FCs, types of disability (moderating factor), and court size.

Statistical analysis

Due to the violation of the requirements for data normality, verified by the Shapiro-Wilk Test, non-parametric analysis was used. A Friedman's ANOVA with Dunn's *post-hoc* was used to compare the athletes' responses in the stages of the simulated effort protocol. Considering the entire protocol performed, athletes from different functional classes (6 classes) Kruskal-Wallis were compared with *post-hoc* Dwass-Steel-Critchlow-Fligner (DSCG). Responses according to court size (2 types) were compared using a Mann-Whitney U Test. The effect size was evaluated by checking Cohen's η^2, considering the following cutoff points, respectively: 0.10 (small), 0.30 (medium), and 0.50 (large); for Cohen's d, and 0.02 (small), 0.15 (medium) and 0.35 (large), to Cohen's η^2.[21] Two multivariate analyses of covariance (MANCOVA) were performed to define the influences of the type of disability on the comparisons between the functional classes and the size of the block used in the simulated effort protocol. An aggregate analysis of the whole group was performed to justify the size of the evaluated sample (sample N). All analyses were performed using the Prism 9 (GraphPad Software Inc., San Diego, CA, USA) and JAMOVI (Jamovi, Sydney, Australia) software, considering a significance level of 5% (P<0.05).

Results

Table I presents the descriptive information of all evaluated athletes, according to demographic data and experience in the modality. In total, 47 athletes were evaluated.

TABLE I.—*Demographic characteristics and PBd experience (N.=47).*

Demographics and sports experience	N. (average±SD), N. (%)
Age (years)	(28.98±10.83)
Gender	
Male	38 (80.85)
Female	9 (19.15)
Functional classification	
WH1	7 (14.89)
WH2	9 (19.15)
SL3	8 (17.02)
SL4	9 (19.15)
SU5	6 (12.77)
SH6	8 (17.02)
Disability type	
Spinal cord	14 (29.79)
Poliomielitis	3 (6.38)
Amputations	4 (8.51)
Congenital malformations	7 (14.89)
Dwarfism	8 (17.02)
Cerebral palsy	7 (14.89)
Les autres	4 (8.51)
Experience time (months)	42.05±68.98
Weekly training routine (days per week)	4.19±1.11
Body mass (kg)	62.93±15.47
Sum of 4 skinfolds (mm)	59.68±29.32
Perceived exertion at the end of the protocol (BORG 0-10)	4.0±2.2

PBd: Parabadminton.

It is noteworthy that a “moderated” value was reported for perceived exertion at the end of the protocol, confirming the suggested intensity.

Comparisons between stages of the experimental protocol

An analyzing the multiple comparisons, it is observed that there are significant differences for VO_2peak ($F_{4, 47}$=16.66; P=0.0008), VO_2avg ($F_{4, 47}$=18.15; P=0.0004), HRmax ($F_{4, 47}$=86.12; P<0.0001), %HRmax ($F_{4, 47}$=86.12; P=0.0001), HRavg ($F_{4, 47}$=101.2; P=0.0001), %CARB ($F_{4, 47}$=41.90; P=0.0001), %FAT ($F_{4, 47}$=42.66; P=0.0001), EEavg ($F_{4, 47}$=19.36; P=0.0002), and EEtotal ($F_{4, 47}$=58.40; P=0.008). *Post-hoc* tests demonstrated significant differences in the physiological variables for VO_2peak between COD1 and RALLY1 (26.67 *vs.* 29.91 mL.kg.min^{-1}); P=0.039), COD2 and RALLY1 (29.91 *vs.* 25.64; P=0.0019), and COD2 and RALLY2 (25.64 *vs.* 28.77; P=0.039); VO_2avg between COD1 and RALLY1 (22.07 *vs.* 25.00 mL.kg.min^{-1}; P=0.0016), RALLY1 and COD2 (25.00 *vs.* 21.15 mL.kg.min^{-1}; P=0.0017), and between COD2 and RALLY2 (21.15 *vs.* 24.01 mL.kg.min^{-1}; P=0.0351); HRmax between COD1 and RALLY1 (152 *vs.* 173 bpm; P<0.0001), COD1 and RALLY2 (152 *vs.* 163 bpm; P<0.0001), RALLY1 and COD2 (173 *vs.* 148 bpm; P<0.0001), and between COD2 and RALLY2 (148 *vs.* 163 bpm; P<0.0001); %HRmax between COD1 and RALLY1 (78 *vs.* 90%; P<0.0001), COD1 and RALLY2 (78 *vs.* 84%; P<0.0001), RALLY1 and COD2 (90 *vs.* 76%; P<0.0001), and between COD2 and RALLY (76 *vs.* 84%; P<0.0001); HRavg between COD1 and RALLY1 (140 *vs.* 161 bpm; P<0.0001), COD1 and COD2 (140 *vs.* 148 bpm; P=0.0437), COD1 and RALLY2 (140 *vs.* 164 bpm; P<0.0001), RALLY1 and COD2 (161 *vs.* 148 bpm; P<0.0001), and between COD2 and RALLY2 (148 *vs.* 164 bpm; P<0.0001). Considering metabolic variables, *post-hoc* analysis showed statistically significant differences for %CARB between COD1 and COD2 (74.83 *vs.* 64.28%; P=0.0164), COD1 and RALLY2 (78.83 *vs.* 64.09%; P=0.0073), RALLY1 and COD2 (80.83 *vs.* 64.28%; P<0.0001), and between RALLY1 and RALLY2 (80.83 *vs.* 64.09%; P<0.0001); %FAT between COD1 and COD2 (25.26 *vs.* 35.72%; P=0.0213), COD1 and RALLY2 (25.26 *vs.* 35.91%; P=0.0096), RALLY1 and COD2 (19.16 *vs.* 35.72%; P<0.0001), and between RALLY1 and RALLY2 (19.16 *vs.* 35.91%; P<0.0001); EEavg between COD1 and RALLY1 (6.622 *vs.* 7.713 kcal; P=0.0242), RALLY1 and COD2 (7.713 *vs.* 6.318 kcal; P=0.0008), and between COD2 and RALLY2 (6.318 *vs.* 7.311 kcal; P=0.0242); EEtotal between COD1 and RALLY1 (53.82 *vs.* 38.61 kcal; P<0.0001), COD1 and RALLY2 (53.82 *vs.* 36.9 kcal; P<0.0001), RALLY1 and COD2 (38.61 *vs.* 48, 71 kcal; P<0.0001), and between COD2 and RALLY2 (48.71 *vs.* 36.9 kcal; P<0.0001).

Comparisons of physiological and metabolic responses between athletes from different FCs

Table II presents data referring to comparisons between athletes from different functional classes evaluated. The Kruskal-Wallis Test showed statistically significant differences for VO_2peak (P=0.0014); VO_2avg (P=0.0003), EEavg (P=0.011), and EEtotal (P=0.022), considering the effect sizes as “great” for VO_2peak, VO_2avg, and EEavg, and “moderate” for EEtotal. The *post-hoc* analysis by the DSCF test showed statistically significant differences for VO_2peak (P=0.075), VO_2avg (P=0.022), EEavg (P=0.011), and EEtotal (P=0.022), between athletes of functional classes WH1 and SL4. Complementarily, MANCOVA identified that there is a significant influence of the type of disability on the analyzed variables (Pillay’s Trace, P=0.005), with a marked effect on VO_2peak (F=3.4935; P=0.010), VO_2avg (F=4.3413; P=0.003), %CARB (F=2.5216; P=0.045), %FAT (F=2.5006; P=0.046), EEavg (F=3.4616; P=0.011), and EEtotal (F=2.4695; P=0.048).

TABLE II.—*Comparisons of physiological and metabolic responses between athletes belonging to different FCs.*

Measures	WH1	WH2	SL3	SL4	SU5	SH6
VO_2peak (mL/min/kg)$^{-1}$	14.5±12.3[#]	20.6±8.73	23.4±3.70	29.6±3.97*[a#]	33.7±19.6	34.4±17.3
VO_2avg (mL/min/kg)$^{-1}$	9.83±10.7[#]	16.2±4.77	20.1±4.48	27.1±5.12*[b#]	28.7±16.8	27.9±13.2
HRmax (bpm)	148±22.2	160±9.93	159±17.6	175±30.4	179±9.17	171±30.2
%HRmax (percent)	72±24.0	83±8.44	83±16.1	90±13.2	89±4.65	88±17.2
HRavg (bpm)	139±23.6	147±12.3	151±18.0	161±26.5	168±10.2	163±25.2
%CARB (percent)	67.1±13.3	66.9±9.86	71.5±11.1	71.3±13.4	78.9±5.02	74.9±7.13
%FAT (percent)	32.9±13.3	33.1±9.86	28.5±11.1	28.8±13.4	21.1±4.57	25.1±7.13
EEavg (kcal)	11.2±12.1[#]	26.2±7.91	27.0±7.73	31.9±8.10*[c#]	32.0±20.7	24.5±10.7
EEtotal (kcal)	77.9±89.6[#]	178±103	178±58.	210±26.6*[d#]	211±142	145±56.5

FCs: functional classes.
*Statistically significant difference identified in individual comparisons by the Kruskal-Wallis Test (P<0.05); [a]size of the effect (η^2=0.31); [b]effect size (η^2=0.39); [c]effect size (η^2=0.35); [d]effect size (η^2=0.27); [#]statistically significant.

TABLE III.—*Comparisons between athletes who performed the simulated effort protocol in two different test conditions (full court* versus *half court).*

Measures	Half court	Full court
VO_2peak (mL/min/kg)$^{-1}$	22.1±11.9	30.4±18.4*[a]
VO_2avg (mL/min/kg)$^{-1}$	17.5±10.2	27.1±13.9*[b]
HRmax (bpm)	159±23.0	177±27.5
%HRmax (percent)	83±13.8	90±11.1*[c]
HRavg (bpm)	147±19.6	166±22.5*[d]
%CARB (percent)	71.0±12.0	75.5±10.1*[e]
%FAT (percent)	29.0±12.0	24.6±9.84*[f]
EEavg (kcal)	22.9±14.9	29.3±13.3*[g]
EEtotal (kcal)	159±114	179±91.1

*Statistically significant difference identified in individual comparisons using the Mann-Whitney U Test (P<0.05); [a]size of effect (η^2=0.60); [b]effect size (η^2=0.66); [c]effect size (η^2=0.36); [d]effect size (η^2=0.40); [e]effect size (η^2=0.39); [f]effect size (η^2=0.41); [g]effect size (η^2=0.25).

Comparisons of physiological and metabolic responses between different court sizes

Table III presents the comparisons between the responses of the athletes who performed the experimental protocol in different court sizes (full and half court). Statistically significant values were identified for VO_2peak (P<0.001), VO_2avg (P<0.001), %HRmax (P=0.032), HRavg (P=0.018), %CARB (P=0.022), %FAT (P=0.022), and EEavg (P=0.016), with a "great" effect for VO_2peak and VO_2avg, and "moderate" for the other variables. Additionally, MANCOVA identified a significant influence of the type of disability on the analyzed variables (Pillay's Trace, P<0.0001), with a marked effect on VO_2peak (F=16.56; P<0.001), VO_2avg (F=19.57; P<0.001), %CARB (F=6.96; P=0.011), %FAT (F=6.90; P=0.012), and EEavg (F=7.07; P=0.011).

Discussion

The main purposes of the present investigation were: 1) to verify the physiological and metabolic responses considering the stages of the experimental protocol, the functional classes of the athletes, and the size of the court used for performance; and 2) to identify the influence of the type of disability on the various comparisons. Our results pointed to significant differences between most phases of the proposed protocol, emphasizing that the experiment was effective in generating significant changes in all physiological and metabolic variables analyzed. Secondly, significant differences were observed when comparing athletes from different FCs, especially from SL4 and WH1 classes (Table II). Additionally, it was found that athletes who performed the protocol on a full court exhibited significantly higher physiological and metabolic responses compared to athletes who performed the effort on a half court (Table III). Finally, in all comparisons (FC and court size), the type of disability significantly influenced the responses found, as verified after analysis through the MANCOVA.

The innovation behind the present investigation resides both in the methodological character of the application of the collection procedures and in the analysis of the data. From the methodological point of view, this was the first study that promoted the execution of a field effort, with continuous monitoring of physiological and metabolic variables in a considerable sample of PBd athletes. In terms of data analysis, the considerable number of evaluated athletes allowed complementary analysis of the effect of the type of disability on the responses found. In turn, the findings found in the present study indicate some very particular effects on these athletes. Such results demonstrate the specificity of responses in PBd athletes, and these findings can be explained by the intermittent nature of the modality,[9] by the biological individuality related to the deficiencies, and by the FC available.

In response to the exercise protocol, it was noticed that the distribution of energetic substrates (CARB and FAT) used during the effort was significantly different between the stages of the protocol. These findings reinforce the metabolic adaptation of PBd athletes, even with different deficiencies and functionalities on the court. It should be noted that all athletes performed the same effort task, with only the size of the court to be used being modified, respecting the specificity of each FC. Even though there was this equalization, it can be observed that the answers found by the athletes were consistent with the need imposed by the modality itself. The variations found for some phases are due to the fact that some PBd athletes exhibit very specific modifications regarding the effects of their own motor disability and energy metabolism, as in the case of athletes with spinal cord injuries[22, 23] and cerebral palsy.[5, 24] Factors such as ataxia, athetosis, hypertonia, in athletes with cerebral palsy, or even autonomic dysfunction in spinal cord injury, are factors that interfere decisively in the acute responses to physical exertion. Even if the athletes are strongly adapted to the exertion performed, as in the case of the athletes included in the present investigation, they can still show significant physiological and metabolic alterations.

Other studies in the field of Paralympic sports have already shown significant differences in the performance of athletes from different FCs,[25, 26] usually due to a current need to develop actions related to sports performance and

evidence-based FC.[27] In collective sports such as basketball, rugby, and sitting volleyball, the functional capacity of athletes is directly related to greater participation in the game and, additionally, to better (and greater) indicators of physical and technical conditioning. Although we found higher values for athletes with higher FCs, the present study only identified statistically significant differences between WH1 and SL4 athletes (Table II). Typically, WH1 athletes are those with less mobility in the trunk region. Those classified as SL4, on the other hand, have minor limitations in the lower limbs, usually below the knees and in just one leg, which allows greater displacements throughout the court. It is noteworthy that only VO_2peak, VO_2avg, EEavg, and EEtotal were higher in SL4 athletes (Table II).

These findings may be strongly related to the reduced mobility of WH1 athletes, especially due to higher spinal cord injuries (above T7) in these athletes, which strongly reduces the functional condition of propulsion in wheelchair sports.[28, 29] The lower the mobility and functional capacity, the lower the amount of muscle mass involved in the manual propulsion gesture and, therefore, the lower indicators of oxygen consumption and, in turn, energy expenditure.[30, 31] In addition to this aspect already evidenced in previous studies, the PBd has characteristics that differentiate it from other sports practiced in wheelchairs. In the game, there is a considerable amount of reverse maneuvers by the athletes, when their opponents use the resource of striking the shuttlecock further into the back of the court. This was even one of the aspects that the effort protocol allowed to simulate. Even so, this specific gesture seems not to have been enough to promote greater metabolic and energy demands of the evaluated athletes. It is worth noting that 14 subjects in our final sample had spinal cord injuries, reinforcing the idea that the level of the injury is influencing these reduced WH1 class results.

There were no significant differences between WH1 or WH2 athletes for the other athletes, although higher values were observed in the SL4 and onwards groups. We do not know for sure the reasons for this behavior. Part of these conditions may, once again, reside in the equalization of the types of disability analyzed, in the case of SH6 athletes (dwarfs), and the low sample size of SU5 athletes (6 athletes). There are no investigations in the literature emphasizing responses at the physiological or metabolic level of people with dwarfism or short stature. However, the allometric effects arising from reduced dimensions and the association between such performance indicators and height may serve as attenuators of the differences found.[32] This information is directly related to the lower values found in VO_2 and EE for SH6 athletes compared to SU5 and SL4 athletes (Table II), even though they are athletes who compete on full court. The fact that no differences were found between classes about HR indicators is in agreement with previous studies that did not observe large associations between HR and VO_2 in conventional athletes.[33] These findings emphasize that the existing non-linear behavior between these variables may also be present in the PBd, even considering the specificities of the athletes.

Limitations of the study

Despite the innovations present in this investigation, some limitations can be highlighted. The absence of an incremental test before the specific effort protocol does not allow comparing the responses according to the "baseline" nor to the individual peak of the athletes. Along the same lines, it was not possible to promote a familiarization session with all the study procedures, including the use of the gas analyzer equipment. Another important detail was the impossibility of controlling the athletes' food intake during the competitive period. Even so, such limitations do not invalidate the results of this investigation. The "baseline" condition was not essential since the athletes were compared to each other, reducing the importance of having peak values to relativize the findings. It is worth noting that all athletes were participating in official competitions, a fact that, at least in part, predicted the best physical and technical level of the study participants. Regarding food intake, all athletes were under the same condition of preparation for carrying out the procedures. Another interesting point is about aggregate statistical analysis (*i.e.*, all athletes), since it can limit some individualized observations by FC. However, we reinforce that future studies should focus especially on borderline FC with a more detailed analysis of the types of disability included in each particular group. Finally, we still recommend that other dimensions of performance be included in the analysis model, such as power and muscle strength, associated with technical and decisive gestures for the modality, such as jumps and smashes. Therefore, it is concluded that PBd athletes respond similarly to conventional athletes without disabilities according to the intermittent demand of the sport, especially in terms of VO_2, HR, and EE. Complementarily, our results also suggest that those athletes belonging to higher FCs and who cover greater distances on the court present greater responses in terms of magnitude compared to athletes with lower motor capacity, especially those who use wheelchairs. Finally, the physiological and metabolic

responses shown in athletes according to FC and court size (distance covered in the stress test) are influenced by the type of disability and its specificities.

Conclusions

From a practical perspective, our results indicate a similar behavior in terms of VO_2, HR, and EE responses in PBd athletes. These findings reinforce that coaches and athletes can implement strategies in their training routines that favor this type of intermittent action, bearing in mind results like the demands of competition. This behavior can be expected in a considerable amount of PBd athletes from different FCs. The exercises and stimulation strategies of these athletes must consider such responses to bring the stimuli even closer to the requirements of the sport. On the other hand, when considering the type of disability, marked differences were observed in some performance variables, especially in VO_2 and EE. In part, the different types of disabilities, their severity, and especially the level of adaptation of athletes to their functionalities will always modulate responses to physical exertion, general or specific. In the PBd, this effect seemed more relevant among the FCs, but it was also present when comparing the athletes who performed the protocol in different court sizes (full and half court). This aspect in particular draws the attention of coaches and functional classifiers to determine the real impacts for each type of disability in particular. It is recommended, therefore, to consider the closest classes to each other (especially WH1-WH2 and SL3-SL4), and that the training routines always consider the type of disability. One last information that may be important concerns the magnitude of energy expenditure responses during the simulated effort. From that point, nutritional demands can be deepened, helping to adjust training programs based on the best relationship between effort and recovery. Probably, each athlete adapted to their functional reality will respond in a very particular way to the intended effort.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions
Saulo F. Oliveira, José I. Oliveira, and Hanno Felder have given substantial contributions to the study conception and design; Saulo F. Oliveira, José I. Oliveira, and Marcelo C. Haiachi contributed to the data acquisition, analysis, and interpretation; all authors equally contributed to the manuscript draft and critical revision for important intellectual content. All authors read and approved the final version of the manuscript.

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