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Brief communication

Heart rate, oxygen uptake, and energy expenditure response of an SL3 class parabadminton athlete to a progressive test and simulated training session: a case study

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Abstract

This investigation demonstrated a routine of evaluation and training of an athlete of the SL3 class of parabadminton for 2 days continuously monitored by a metabolic analyzer with measurements of oxygen consumption ($\dot{V}O_2$), carbon dioxide production, and heart rate (HR). The results showed HR and $\dot{V}O_2$ responses varying between 50% and 99.54% of HRmax (mean HR 80.92 bpm), and 6% and 104% (mean $\dot{V}O_2$ 35.25 mL/kg/min) of $\dot{V}O_2$max, during the simulated game. The exercise test and the simulated training session showed significant changes in HR and $\dot{V}O_2$, reinforcing the need for considerable energy input to training and assessment.

Key words: Paralympic sport, racket sports, sports physiology, athletic training, performance

Résumé

Cette étude a démontré une procédure d'évaluation et d'entraînement d'un athlète de la classe SL3 de Para-Badminton pendant deux jours. L'athlète est évalué en continu au moyen d'un analyseur métabolique pour la mesure de la consommation d'oxygène (« $\dot{V}O_2$ »), de la production de dioxyde de carbone et de la fréquence cardiaque (« HR »). Les résultats ont présenté lors du jeu simulé des réponses HR et $\dot{V}O_2$ variant entre 50 et 99,54 % de HRmax (HR, moyenne 80,92 bpm) et 6 et 104 % ($\dot{V}O_2$ moyenne 35,25 mL/kg/min) de la $\dot{V}O_{2max}$. Le test d'effort et la séance d'entraînement simulée ont révélé des changements significatifs dans la fréquence cardiaque et le $\dot{V}O_2$. Ces données accentuent la nécessité d'un apport énergétique considérable à l'entraînement et à l'évaluation. [Traduit par la Rédaction]

Mots-clés : sport paralympique, sports de raquette, physiologie du sport, entraînement sportif, performance

Introduction

Para-Badminton or Parabadminton (PBd) had its official debut at the Paralympics in Tokyo 2020 (www.paralympic.org). It is important to highlight that the modality has basic rules such as adaptations to the playing court and additional equipment, according to the classification of players and events (BWF Statutes 2021). In addition, PBd athletes use a racket to dispute singles or doubles in five events—male and female singles, male and female doubles, and mixed doubles (BWF Statutes 2021)—each requiring specific preparation in terms of technique, control, and physical fitness.

Thus, due to the demand for the sport, it is logical to think that PBd athletes need periodic cardiorespiratory assessments (Strapasson et al. 2019). Olympic badminton is composed of interminable actions, requiring athletes considerable levels of energy supply, supplying aerobic and anaerobic needs (Phomsoupha and Laffaye 2015). Thus, the decisive moments of the games are supplied by the anaerobic metabolism, being the total time of the activity and the intervals of recovery supplied by the aerobic metabolism. Although we know the energetic needs of badminton, until now the metabolic and physiological responses of PBd athletes are not known.

Several instruments are available for this assessment, especially portable equipment that allows for measuring the oxygen uptake volume ($\dot{V}O_2$), carbon uptake volume ($\dot{V}CO_2$), respiratory quotient (RQ), and minute ventilation ($\dot{V}E$) (Guidetti et al. 2018; Tsekouras et al. 2019). With the data in hand, respiratory variables can become readily available for coaches to monitor long-term cardiorespiratory fitness by planning periodization aimed at optimal athlete performance (da Cunha et al. 2011).

Thus, given the metabolic requirement imposed by the game and the need for scientific and technological development for the modality, the present case study aims to demonstrate the responses of an experienced PBd athlete with cerebral palsy (class SL3) to a standardized assessment and training routine (Halperin 2018). As an initial hypothesis, we believe that the results presented by the evaluated athlete may be similar to those exhibited by Olympic athletes in terms of behavior but present acute responses of lower magnitude due to peculiar characteristics of cerebral palsy.

Case report

Athlete and case-study background

The evaluated athlete (L.R.S.; 22 years old; male; black; weight: 67 kg; height: 1.71 m; body mass index: 22.91; hypertonia level 3, Ashworth Scale) has 5 years of experience in the sport, participating in regional tournaments. He was diagnosed with cerebral palsy (CP), where the greatest involvement is on the left side of the body, predominantly in the left leg. He has hypertonia in his left leg and moderate ataxia in his left arm. The right side of the body remains functional without changes caused by cerebral palsy. The study was carried out on 2 days, separated by an interval of 1 week. On day 1, an evaluation of the aerobic capacity was carried out, through a progressive field test. On day 2, a simulated training session was performed, with lateral and longitudinal displacements to hit the shuttlecock against the opponent's court. On both days, the $\dot{V}O_2$ and heart rate (HR) were monitored by telemetry. All procedures were performed in the afternoon, where the individual was fed, as usual, 2 hours after his last meal. The study was approved by the University Federal of Pernambuco Ethics Committee (no. 52763121.0.0000.9430). The participant received a clear explanation of the research procedures and signed an informed consent document prior to participation.

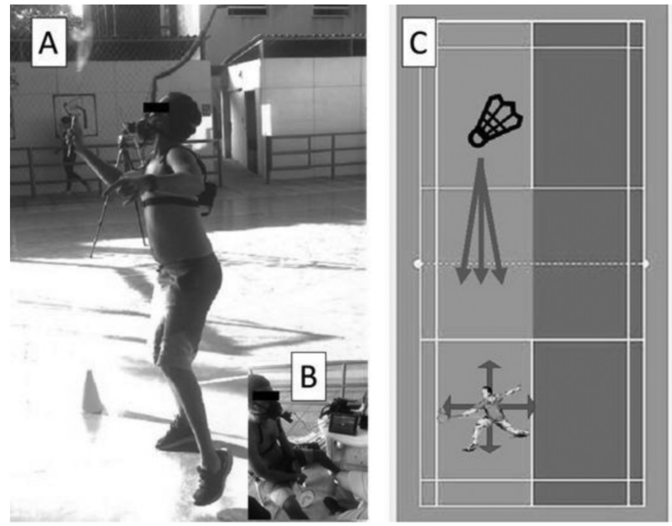
Maximum progressive aerobic test

On the first day, the field progressive velocity protocol (WHEEL-PROFT), was used and adapted by Vanlandewijck et al. (2006). The participant walked a distance of 15 m repetitively, delimited by two lines, walking the distance at a pace defined by audible beeps, starting at 5 km/h speed with a 0.5 km/h increase every minute. When the participant was unable to reach the target line twice consecutively, the test was terminated. In the end, the distance covered (excluding the length not reached by the athlete when giving up) and the time spent were recorded. The test measure was given by the final distance covered, the level reached, and the total time of each target reached in the protocol.

Simulated training routine

On the second day, a simulated PBd training/competition session was held. Before the session, a period of 5 minutes was set aside for the athlete to warm up, as usually performed by a volunteer. In the center, on the opposite side of the court, a coach was positioned with 24 shuttlecocks in hand. At each throw by the coach, the athlete returned the shuttle by swiping his racket to the opposite side of the court. The direction of the throw performed by the coach allowed small lateral (right–left) and longitudinal (front–rear) displacements. After the sequence of 24 shuttlecocks was completed, a rest time ranging between 30 and 60 s was considered for the replacement of shuttlecocks and the restart of automated launches. During both conditions, $\dot{V}O_2$, $\dot{V}CO_2$ production, HR, and the athlete's movement were continuously monitored. The entire training session lasted about 25 minutes, with 13 minutes being reserved exclusively for the simulated exercise. Among the 13 minutes of activity, 6:30 min:s was reserved for lateral displacements, and the rest of the time was reserved for longitudinal displacements. Figure 1 shows an illustration of the logistics used to carry out the simulated session.

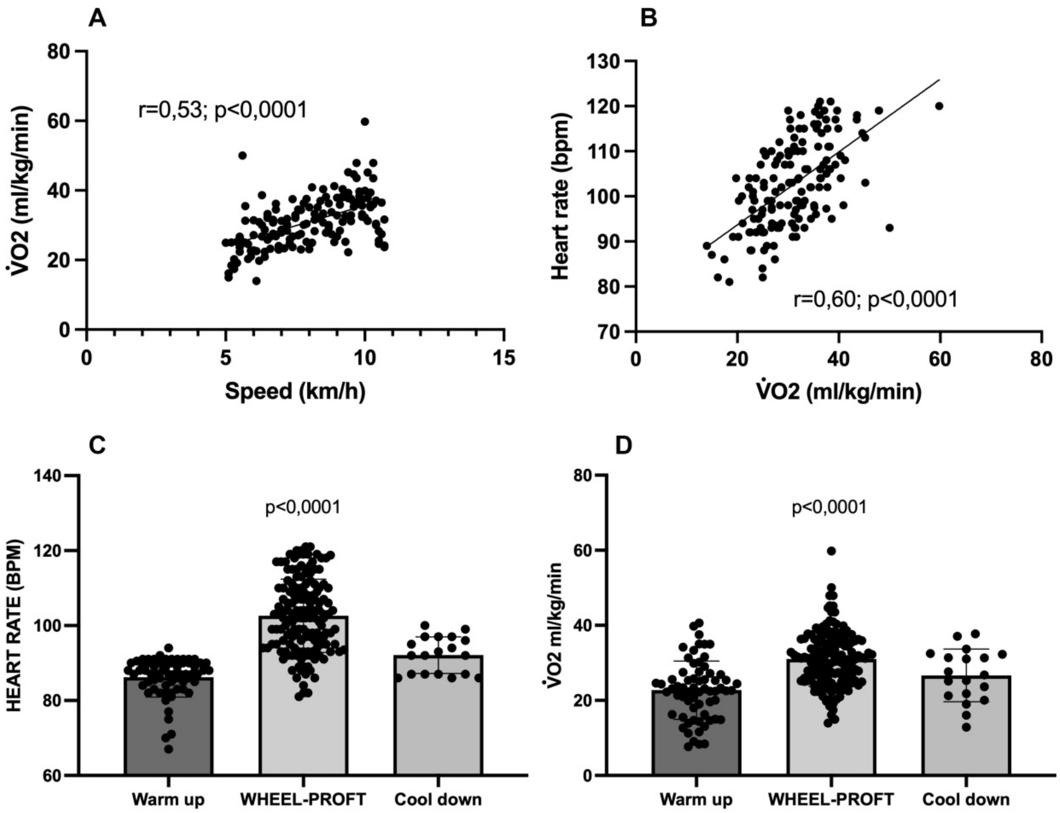
Fig. 1. Diagram of the simulated training session with lateral and longitudinal displacements. (A) Photo of the athlete performing the strike to return the shuttlecock; (B) the athlete at rest and familiarizing himself with the portable equipment for metabolic assessment by telemetry; and (C) organization of the court and directions of the launches and displacements of the shuttlecock and the athlete.



Measurements of oxygen consumption and energy expenditure

The measurement of metabolic demand was obtained using a portable PNOĒ analyzer system (ENDO Medical, USA). The PNOĒ is a portable metabolic device designed to measure gas exchange and validated for laboratory and field conditions (Tsekouras et al. 2019). The unit runs on lithium batteries and weighs approximately 800 g. The device consists of a single carcass (120 mm × 110 mm × 45 mm, height, width, and length, respectively), attached to a shoulder strap and carried by the subject during physical effort. The subject wears a suitable mask and breathes through the hot-film anemometer flow sensor. HR and respiratory gases are transmitted by telemetry. The PNOĒ operates in a breath-by-breath mode that continuously measures the volume and determines exhaled gas concentrations simultaneously. It measures $\dot{V}O_2$ using an open-circuit indirect calorimetry tech-

Fig. 2. Correlations and comparisons of cardiovascular parameters (HR) and $\dot{V}O_2$ during the WHEEL-PROFT progressive exercise protocol (A, B) and the simulated training (C, D).



nique, evaluating pulmonary gas exchange in the mouth and nose. The unit's components include an electrochemical $\dot{V}O_2$ analyzer and an infrared carbon (CO_2) analyzer. The PNOĒ arrangement was used on the first day, during the aerobic conditioning assessment, and on the second day in the simulated experimental sessions. Energy expenditure was estimated using the indirect calorimetry technique, considering a metabolic equivalent in kilocalories for each liter of $\dot{V}O_2$ consumed. The values of $\dot{V}O_2$ and CO_2 were crossed to determine the RQ and subsequent contribution of carbohydrates and fat during the exercise protocol.

Data analysis

The normality of all the data collected from the volunteer was analyzed using the Shapiro–Wilk test. Data obtained continuously in the progressive test and the simulated training session were analyzed using Pearson's correlation. The phases of the aerobic exercise protocol (warming up, the testing itself, and cooling down) were compared with each other using a fixed-effects model. The values of HR reached in the effort test were transformed into percentages of HRmax (Tanaka et al. 2001). Similarly, the $\dot{V}O_2$ values displayed in response to the training protocol were transformed into percentages of the maximum capacity achieved in the progressive exercise test. The responses of the parameters evaluated during the training session (HR and $\dot{V}O_2$) were compared between the moments of lateral and longitudinal displacements using a paired *t* test. All analyses were performed using the Prism statistical package, version 9.0 (GraphPad, USA), and a significance level of 5% ($p < 0.05$) was considered.

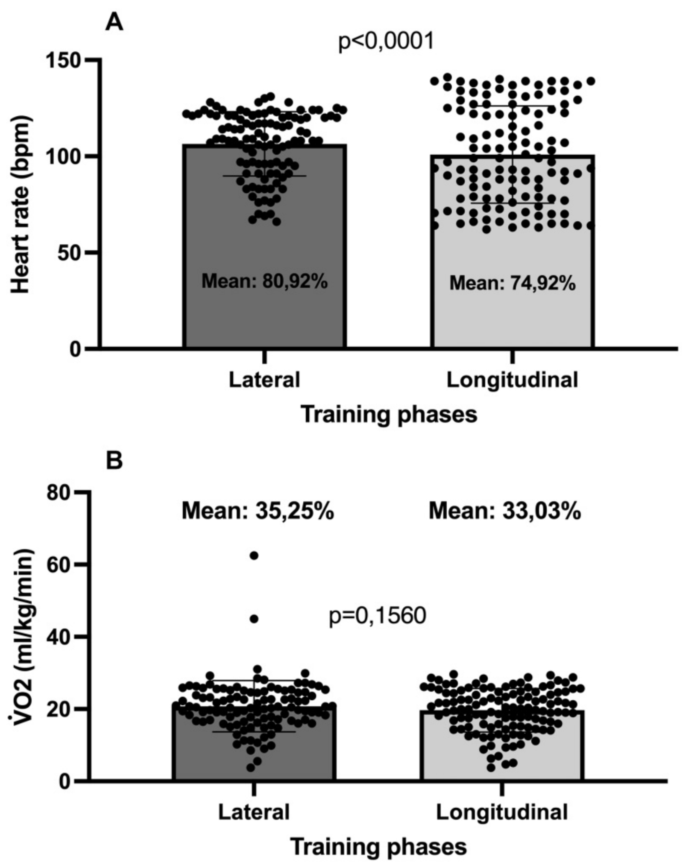
Observations and outcomes

Figure 1 shows details of the athlete participating in the simulated training session, in addition to a diagram demonstrating the experimental protocol developed at the training site. Through the effort test performed, it was verified that the data obtained from the progressive speed were significantly correlated with the athlete's $\dot{V}O_2$. In turn, the HR was also correlated with $\dot{V}O_2$ consumption throughout the progressive exercise protocol (Fig. 2A and 2B, respectively). When comparing the phases of the progressive exercise protocol, significant differences were found between the three moments, demonstrating the significant acute effect of the proposed protocol ($F_{[0.9758,40.01]} = 118.9$, $p < 0.0001$, Fig. 2C). A similar effect was verified when comparing the behavior of $\dot{V}O_2$ between the three phases of the protocol ($F_{[1780,72.97]} = 26.78$, $p < 0.0001$, Fig. 2D).

When verifying the responses to the simulated training session, significant differences were found between the phases of lateral and longitudinal displacements only for the individual's HR ($p < 0.0001$, Fig. 3A) No differences were observed in the consumption of $\dot{V}O_2$ between the two phases of the training protocol ($p = 0.1560$, Fig. 3B).

From a descriptive point of view, the total energy expenditure of 84.26 kcal accumulated throughout the activity was

Fig. 3. HR (A) and $\dot{V}O_2$ (B) responses to a simulated exercise protocol for an SL3 class PBd athlete. The percentages of HR and $\dot{V}O_2$ were properly relativized according to the maximum values as recommended by Tanaka et al. (2001) and by the maximum progressive test performed, respectively.



verified. In addition, it was found that during the simulated protocol there was a higher mean contribution of carbohydrate metabolism for both phases (lateral and longitudinal displacement), compared with the contribution of lipids (lateral: 0.35 kcal vs. 0.03 kcal; longitudinal: 0.32 kcal vs. 0.04 kcal).

Discussion

The main objective of this case study was to show a training routine to present the possibilities of monitoring and evaluation of an experienced athlete, of class SL3. PBd already has a presence in the 2024 Summer Paralympics and, despite the similarities to Olympic badminton, to date, there is no information on metabolic and cardiovascular responses to standardized exercise protocols in PBd. Therefore, an evaluation with the portable instrument of gas exchange analysis applied in a simulated game protocol showed the acute responses in a PBd with cerebral palsy. These findings partially corroborate our initial hypothesis of approximation with the acute responses of an Olympic badminton athlete, although significant differences were observed between the stages of the effort protocol (between HR and $\dot{V}O_2$), and during the simulated game (only in HR).

Therefore, the main result observed for the aerobic effort test was that the progressive speed of the athlete was significantly correlated with the consumption of $\dot{V}O_2$ ($r = 0.53$; $p < 0.01$). In turn, the HR was also correlated with $\dot{V}O_2$ consumption throughout the progressive exercise protocol ($r = 0.60$; $p < 0.01$). This can be explained by the cardiorespiratory demand imposed by the modality. For example, understanding that badminton is a modality with parameters similar to those of PBd, it can be seen that the average HR of an athlete in this modality can reach more than 90% of the maximum HR. Also, the aerobic system requirement during a game can reach 60%–70% (Phomsoupha and Laffaye 2015).

These findings may indicate the possibility of using HR as a parameter for monitoring exercise intensity, even for athletes with cerebral palsy. With the advancement of portable technologies, studies with ecological designs should be developed for this purpose (Cardinale and Varley 2017). However, the $\dot{V}O_2$ and HR responses in the athlete studied showed lower values (mean HR: 80.92 bpm; mean $\dot{V}O_2$: 35.25 mL/kg/min) than those verified in other studies carried out with Olympic athletes (Esteve-Lanao et al. 2007). This can be explained, at least in part, by factors specific to cerebral palsy.

Puce et al. (2021) summarized that fatigue information measured objectively on maximal task performance and indicated lower levels in participants with CP, possibly due to their pathological inability to recruit highly fatigable muscle fibers. However, highly trained individuals with CP compared with neurotypical people performing maximally fatiguing tasks seem to be an exception to this as they exhibit similar levels of fatigue. In submaximal tasks, such as the one performed in the present study, other factors may influence the metabolic responses of athletes with CP, such as ataxia, athetosis, or hypertonia. Thus, the individualized responses of each athlete must be considered in the planning of effort intensities and, above all, in their recovery.

When comparing the phases of the progressive exercise protocol (warm-up, activity, and rest), significant differences were observed between the three moments ($p < 0.01$) and in the $\dot{V}O_2$ behavior ($p < 0.01$), demonstrating the acute responses of a standardized PBd training session. The evaluated athlete presented a total energy expenditure of 84.26 kcal/min, with a predominance of carbohydrate consumption as an energy source (fat: 0.50; carb: 2.08 kcal/min). It is worth mentioning that the protocol time (13 minutes) was approximately equivalent to a set of PBd. These findings reinforce the importance of similar assessment protocols for the development of an athlete whose aerobic system requirements for performance are very well known. It is known that a well-developed aerobic endurance capacity seems necessary for quick recovery after intensive training (Faude et al. 2007).

Regarding the responses to the simulated training session, significant differences were found between the phases of lateral and longitudinal displacements only for HR ($p < 0.01$). Similarly, in investigations with badminton, the relevance of HR as one of the indicators related to performance in matches is clear (Bisschoff et al. 2018). Because of the increased HR, long-term badminton matches can lead to neuromuscular fatigue (Girard and Millet 2009). Accumulated neuromuscular fatigue negatively affects players' ability to execute blows with optimal strength and accuracy, and can also lead to less reactive court moves and poor tactical choices during matches. It should be highlighted that, based on a good metabolic assessment, PBd athletes and coaches can anticipate these parameters with adequate preparation. Additionally, our findings may serve as parameters to replicate similar protocols for other athletes with disabilities and other functional classes.

Conclusions

It was observed that the PNOĒ instrument was sufficiently reliable and discriminating in its metabolic assessments of a PBd athlete. Similarly, the protocol intervention was also effective for physical assessment. The authors realized that the presented routines were sufficient to generate a considerable physiological and metabolic demand on the investigated athlete. Both the exercise test and the simulated training session were able to generate significant changes in HR and $\dot{V}O_2$, reinforcing the need for considerable energy input to compose assessment and training routines. In future perspectives, new studies with PNOĒ in different functional classes of PBd should be carried out to guarantee the reproducibility of the instrument for the modality. Finally, the authors recommend periodic metabolic assessments of PBd athletes.

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Any data request should be addressed to the corresponding author.

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Author contributions

Conceptualization: SFMO, JIVO, MH, and HF; investigation: SFMO and JIVO; formal analysis: SFMO; writing—original draft and review & editing—SFMO, JIVO, MH, and HF. All the authors read and approved the final version of the manuscript.

Competing interests

The authors have declared that there are no competing interests.

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References

Bisschoff, C.A., Coetzee, B., and Esco, M.R. 2018. Heart rate variability and recovery as predictors of elite, African, male badminton players' performance levels. Int. J. Perform. Anal. Sport, **18**(1): 1–16. doi: 10.1080/24748668.2018.1437868.

BWF Statutes. 2021. Instructions to technical officials.

Cardinale, M., and Varley, M.C. 2017. Wearable training-monitoring technology: applications, challenges, and opportunities. Int. J. Sports Physiol. Perform. **12**(S2): 55–62. doi: 10.1123/ijspp.2016-0423.

da Cunha, F.A., Farinatti, P.de T.V., and Midgley, A.W. 2011. Methodological and practical application issues in exercise prescription using the heart rate reserve and oxygen uptake reserve methods. J. Sci. Med. Sport, **14**(1): 46–57. doi: 10.1016/j.jsams.2010.07.008. PMID: 20833587.

Esteve-Lanao, J., Foster, C., Seiler, S., and Lucia, A. 2007. Impact of training intesity distribution on performance in endurance athetes. J. Strength Cond. Res. **21**(3): 943–949. PMID: 17685689.

Faude, O., Meyer, T., Rosenberger, F., Fries, M., Huber, G., and Kindermann, W. 2007. Physiological characteristics of badminton match play. Eur. J. Appl. Physiol. **100**(4): 479–485. doi: 10.1007/s00421-007-0441-8. PMID: 17473928.

Girard, O., and Millet, G.P. 2009. Neuromuscular fatigue in racquet sports. Phys. Med. Rehabil. Clin. North Am. **20**(1): 161–173. doi: 10.1016/j.pmr.2008.10.008. PMID: 19084769.

Guidetti, L., Meucci, M., Bolletta, F., Emerenziani, G.P., Gallotta, C.M., and Baldari, C. 2018. Validity, reliability and minimum detectable change of COSMED K5 portable gas exchange system in breath-by-breath mode. PLoS One, **13**(12): 1–12. doi: 10.1371/journal.pone.0209925.

Halperin, I. 2018. Case studies in exercise and sport sciences: a powerful tool to bridge the science-practice gap. Int. J. Sports Physiol. Perform. **13**(6): 824–825. doi: 10.1123/ijspp.2018-0185. PMID: 29929417.

Phomsoupha, M., and Laffaye, G. 2015. The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. Sports Med. **45**(4): 473–495. doi: 10.1007/s40279-014-0287-2. PMID: 25549780.

Puce, L., Pallecchi, L., Chamari, K., Marinelli, L., Innocenti, T. Pedrini, R., et al. 2021. Systematic review of fatigue in individuals with cerebral palsy. Front. Hum. Neurosci. **15**: 598800. doi: 10.3389/fnhum.2021.598800. PMID: 33790748.

Strapasson, A.M., Fonseca, K., Alves, M., Haegeler, J., and Duarte, E. 2019. Initiation of para-badminton through the "Shuttle time" teaching program. Conexões: Educação Física, Esporte e Saúde, **17**: 1–12. doi: 10.20396/conex.v17i0.8655265.

Tanaka, H., Monahan, K.D., and Seals, D.R. 2001. Age-predicted maximal heart rate revisited. J. Am. Coll. Cardiol. **37**(1): 153–156. doi: 10.1016/s0735-1097(00)01054-8. PMID: 11153730.

Tsekouras, Y.E., Tambalis, K.D., Sarras, S.E., Antoniou, A.K., Kokkinos, P., and Sidossis, L.S. 2019. Validity and reliability of the new portable metabolic analyzer PNOE. Front. Sports Act. Living, **1**: 1–7. doi: 10.3389/fspor.2019.00024. PMID: 33344925.

Vanlandewijck, Y., Van De Vliet, P., Verellen, J., and Theisen, D. 2006. Determinants of shuttle run performance in the prediction of peak VO_2 in wheelchair users., Disabil. Rehabil. **28**(20): 1259–1266. doi: 10.1080/09638280600554769. PMID: 17083172.