Sport-specific field tests vs. lactate threshold velocity: practical application for aerobic evaluation in badminton athletes

Pruebas de campo específicas vs. la velocidad umbral de lactato: aplicación práctica para la evaluación aeróbica en atletas de bádminton

Authors

Gabriel Henrique Ornaghi de Araujo [1]
Cecília Segabinazi Peserico [2]
Layla Maria Campos Aburachid [3]
Fabiana Andrade Machado [1]

[1] State University of Maringá, Brazil
[2] State University of Londrina, Brazil
[3] Federal University of Mato Grosso, Brazil

Corresponding Author:
Gabriel Henrique Ornaghi de Araujo
ornaghi.gabriel7@gmail.com

Received: 10-04-26
Accepted: 29-05-26

How to cite in APA

Ornaghi de Araujo, G. H., Segabinazi Peserico, C., Campos Aburachid, L. M., & Andrade Machado, F. (2026). Sport-specific field tests vs. lactate threshold velocity: practical application for aerobic evaluation in badminton athletes. *Retos, 81*, 853-862. https://doi.org/10.47197/retos.v81.119223

Abstract

Objective: This study aimed to examine the relationship and agreement between aerobic fitness assessed through specific field tests and the velocity associated with lactate threshold (vLT) in male badminton athletes. The second aim was to compare the physiological and psychophysiological variables between specific field tests and the vLT.
Methodology: Sixteen national-level male badminton athletes completed an incremental treadmill test to determine vLT, followed by the three specific field tests (Abian Intermittent Recovery Badminton Test – AIR-BT; Badminton Specific Incremental Test – BST; and the Yo-Yo Intermittent Recovery Test Level 1 – Yo-Yo IR1) in randomized order. The blood lactate concentration was assessed to obtain the [La] peak (La_{peak}), the heart rate (HR) was continuously monitored to determine mean and maximum HR (HR_{mean} and HR_{max}), and the rating of perceived exertion (RPE) was recorded to determine maximum value (RPE_{max}).
Results: Physiological and psychophysiological responses differed between protocols, with lower HR_{max}, HR_{mean}, LA_{peak}, and RPE_{max} observed in the BST. The AIR-BT showed a very large correlation with vLT (r = 0.79), whereas the BST and Yo-Yo IR1 demonstrated moderate correlation with vLT (r = 0.49 and 0.42, respectively). The AIR-BT, BST, and Yo-Yo IR1 showed a mean bias of -0.001, -0.03, and -0.04 $km{\cdot}h^{-1}$, with limits of agreement ranging from -0.91 to 0.90, 0.003 to 1.168, and -1.345 to 1.354 $km{\cdot}h^{-1}$, respectively.
Conclusions: The AIR-BT presents the highest correlation and agreement with vLT compared to other field tests, highlighting the importance of this specific test in assessing aerobic fitness in badminton.

Keywords

Aerobic capacity; physiology; physical fitness; racquet sports; specific testing.

Resumen

Objetivo: Este estudio tuvo como objetivo examinar la relación y la concordancia entre la aptitud aeróbica evaluada mediante pruebas de campo específicas y la velocidad asociada al umbral de lactato (vLT) en atletas masculinos de bádminton. El segundo objetivo fue comparar las variables fisiológicas y psicofisiológicas entre las pruebas de campo específicas y el vLT.
Metodología: Dieciséis atletas masculinos de bádminton de nivel nacional completaron una prueba incremental en cinta rodante para determinar el vLT, seguida de tres pruebas de campo específicas (Abian Intermittent Recovery Badminton Test – AIR-BT; Badminton Specific Incremental Test – BST; y el Yo-Yo Intermittent Recovery Test Level 1 – Yo-Yo IR1) en orden aleatorio. Se evaluó la concentración de lactato en sangre para obtener el pico de [La] (La_{peak}), se monitorizó continuamente la frecuencia cardíaca (FC) para determinar la FC media y máxima (FC_{mean} y FC_{max}), y se registró la escala de esfuerzo percibido (RPE) para determinar el valor máximo (RPE_{max}).
Resultados: Las respuestas fisiológicas y psicofisiológicas difirieron entre los protocolos, observándose valores más bajos de FC_{max}, FC_{mean}, LA_{peak} y RPE_{max} en la prueba BST. La prueba AIR-BT mostró una correlación muy alta con vLT (r = 0,79), mientras que la BST y la prueba Yo-Yo IR1 demostraron una correlación moderada con vLT (r = 0,49 y 0,42, respectivamente). La AIR-BT, la BST y la prueba Yo-Yo IR1 mostraron un sesgo medio de -0,001, -0,03 y -0,04 $km{\cdot}h^{-1}$, con límites de concordancia que oscilaron entre -0,91 y 0,90, 0,003 y 1,168, y -1,345 y 1,354 $km{\cdot}h^{-1}$, respectivamente.
Conclusiones: La prueba AIR-BT presenta la mayor correlación y concordancia con vLT en comparación con otras pruebas de campo, lo que subraya la importancia de esta prueba específica para evaluar la aptitud aeróbica en bádminton.

Palabras clave

Capacidad aeróbica; fisiología; condición física; deportes de raqueta; pruebas específicas.

Introduction

High-level badminton performance requires anaerobic efforts during high-intensity rallies, interspersed with aerobic efforts and short rest periods (Winata et al., 2025; Cádiz Gallardo et al., 2023). During badminton matches, athletes exhibit high cardiovascular and metabolic demands, performing approximately 50% of match time between 75 and 100% of maximum heart rate (HR_{max}) and at intensities above 70% of maximal oxygen uptake ($\dot{V}O_{2max}$) (Madsen et al., 2016; Phomsoupha and Laffaye, 2015). Due to the long periods of effort during a match (*i.e.,* ≈ 40 min), aerobic metabolism plays an important role in maintaining sprint quality and sustaining high performance, optimizing recovery between rallies and games (Winata et al., 2025; Cádiz Gallardo et al., 2023; Phomsoupha and Laffaye, 2015). Over the years, different field tests have been developed to assess the aerobic fitness of badminton athletes, to evaluate physical adaptations, and prescribe more efficient training sessions (Abián-Vicén et al., 2021; Madsen et al., 2016; Fuchs et al., 2014; Wonisch et al., 2003).

Among the field protocols used, the most accessible (*i.e.,* that do not require expensive technologies) are the Abian Intermittent Recovery Badminton Test (AIR-BT) (Abián-Vicén et al., 2021), the Badminton Specific Incremental Test (BST) (Wonisch et al., 2003), and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Bangsbo et al., 2008). In badminton-specific field protocols, athletes perform short, multidirectional movements on a badminton court (≈ 3 – 5 m), whereas the Yo-Yo test involves only linear running outside the court, despite being widely used to assess badminton athletes (Madsen et al., 2021; Liu et al., 2021). Through these protocols, aerobic fitness in badminton athletes can be determined, with performance typically characterized by variables such as maximal velocity achieved (V_{max}), total distance covered, and time to exhaustion (Madsen et al., 2016; Abián-Vicén et al., 2021).

Although field protocols are widely used due to their applicability and sport specificity, laboratory-based assessments remain important for assessing physiological variables related to aerobic fitness (Peserico et al., 2021; Billat, 1996). Among these variables, the lactate threshold (LT) is frequently used to evaluate aerobic fitness and to guide training prescription in athletes (Casado et al., 2023; Billat, 1996). In incremental exercise protocols, the velocity associated with LT (vLT) provides an indicator of aerobic capacity and has been applied to characterize physiological responses to exercise (Støa et al., 2020; Peserico et al., 2018; Faude et al., 2009). While several sport-specific field tests have been used to assess aerobic fitness in badminton players, the relationship and agreement between these field-based tests and vLT remain unknown.

Abián-Vicén et al. (2021) developed the AIR-BT as a practical and sport-specific incremental field protocol to estimate aerobic fitness in badminton players. Strong correlations were found between AIR-BT performance and laboratory-measured $\dot{V}O_{2max}$($r = 0.87$), as well as with performance in the Yo-Yo IR1 ($r = 0.86$), with no significant differences between measured and predicted $\dot{V}O_{2max}$. Similarly, Wonisch et al. (2003) reported a significant correlation between BST and the maximal lactate steady state (MLSS), particularly for HR ($r = 0.78$) and velocity ($r = 0.93$) in the MLSS, supporting its validity for assessing aerobic capacity. Furthermore, Madsen et al. (2016) developed the B-ENDURANCE test and showed that performance discriminates competitive levels and correlates with national ranking ($r = 0.80$), supporting its relevance for assessing badminton-specific endurance.

Despite the demonstrated validity of badminton-specific field tests such as the AIR-BT and BST, these protocols differ in their structural characteristics, including movement patterns, stimulus progression, and work-to-rest ratios, which may elicit distinct physiological and performance responses (Abián-Vicén et al., 2021; Wonisch et al., 2003; Madsen et al., 2016). Furthermore, most studies have focused primarily on maximal or performance-based outcomes, such as $\dot{V}O_{2max}$, HR responses, or time to exhaustion. However, from a physiological and training perspective, submaximal markers such as the vLT may provide more sensitive and practical information for exercise prescription and monitoring (Fischer et al., 2025; Casado et al., 2023).

In this context, the vLT represents a key parameter for defining aerobic capacity and individualizing training intensity domains (Casado et al., 2023; Peserico et al., 2021; Billat, 1996). Specifically, the relationship and level of agreement between field-based tests (*e.g.,* AIR-BT, BST, and Yo-Yo IR1) and vLT were not investigated in badminton athletes. Therefore, this study aimed to examine the relationship and agreement between aerobic fitness assessed through specific field tests and the vLT in male badminton athletes. In addition, a second aim was to compare the physiological and psychophysiological variables between specific field tests and the vLT. We hypothesized that specific field tests would show a high relationship and good agreement with vLT, and different physiological and psychophysiological responses between tests.

Method

Participants

Sixteen national-level badminton men's athletes (age: 18.6 ± 2.3 years, height 173.7 ± 6.7 cm, weight 66.3 ± 7.0 kg, body mass index 21.9 ± 1.9 kg·m^{-2}, and body fat 16.0 ± 4.7 %) participated in this cross-sectional study. All athletes were classified as tier 3 (*i.e.,* Highly Trained/National Level) according to McKay et al. (2022). The exclusion criteria were not completing all assessment protocols and getting injured during the study. Before the study, the athletes and their parents were informed about the testing and training procedures and the possible risks involved, and they provided written informed consent. The Human Research Ethics Committee approved this study (#5643356/2022). All research was conducted ethically according to the Helsinki Declaration.

Experimental Design

After the familiarization process with the treadmill and field tests, each participant performed a maximal incremental treadmill test to determine vLT, and three randomly ordered field tests to determine aerobic fitness at the same time of the day under similar climatic conditions (temperature = 25–29 ◦C and relative humidity = 60–75%), with an interval of 48 h between each test. They were instructed to report for testing well rested, well hydrated, and wearing lightweight, comfortable clothing, and also to avoid eating 2 h before the maximal exercise tests, to abstain from caffeine and alcohol, and to refrain from strenuous exercise for 24 h before testing (Machado et al., 2013). All of the participants were verbally encouraged throughout the tests.

Procedures

Velocity at Lactate Threshold (vLT)

The velocity of LT occurrence (vLT) was determined during a maximal incremental running test performed on a multiprogrammable automatic treadmill (Inbramed® Super ATL, Porto Alegre – Brazil). The protocol was preceded by a three-minute warm-up at 6 km·h^{-1} and starting at 8 km·h^{-1} with increments of 1 km·h^{-1} every three minutes (Machado et al., 2013). The test was continued until maximum voluntary exhaustion, and participants were verbally encouraged to maintain effort for as long as possible. Blood samples (25µl) were collected from the earlobe to determine blood lactate concentrations ([La]) between each stage of the test with 15 s pauses (Alves et al., 2017). To determine the vLT of each athlete, the present study used the maximum deviation method (D_{max}) (Cheng et al., 1992), which is an objective and individualized method that considers the [La] responses and the velocities (km·h^{-1}) of each stage (Alves et al., 2017).

Abian intermittent recovery badminton test (AIR-BT)

The AIR-BT is a maximal incremental protocol with 16 intensity stages performed on an official badminton court (Abián-Vicén et al., 2021). In each movement, the dominant foot must cross a line placed in each of the four corners of the singles badminton court, returning to the center of the court after each movement. Stages one and two have a sequence of movement; from stage three to seven, there are three sequences; from stage eight to 12, there are four sequences; and from stage 13 to 16, there are six sequences, with time gradually decreasing between stages. Stage one has a frequency of 18 signals·min^{-1}, and the frequency increases by 1 signal·min^{-1} in each stage (from 18 signals in stage one to 33 signals in stage 16). Between each sequence and between each stage, participants have a recovery time of 10 s (Abián-Vicén et al., 2021). The test is continued until participants reach voluntary exhaustion or the second time the participant is unable to reach the intermediate position at the correct time. Test performance was determined by the total test duration, total distance covered, and maximum velocity (V_{max}). V_{max} was determined based on the calculation of the average velocity (*i.e.*, distance/time) corresponding to the stage at which the test was completed.

Badminton Specific Incremental Test (BST)

The BST consists of a maximal incremental protocol performed on an official badminton court, in which the athletes need to move to three specific points: two points on the net (right and left), and one point in the central region of the back of the court (Wonisch et al., 2003). From a central point, participants, with a signal given by a whistle, must advance 3 meters to a marker on the right side of the court, touch the net with the racket, and immediately return to the central point. At the next signal, participants move to a second marker on the left side of the court and return to the center point. They then move backward to a third marker, three meters behind the center point, performing a jump turn along the center line while simulating performing a smash. The speed at the beginning of the test is 0.60 $m \cdot s^{-1}$, according to six signals·min^{-1}. Throughout the test, the speed gradually increases every minute by 0.10 $m \cdot s^{-1}$, that is, each stage of the test lasts one minute. The test is performed continuously until maximum voluntary exhaustion. The variables to determine performance in the BST test were the same used in the AIR-BT.

Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1)

The Yo-Yo IR1 consists of a back-and-forth regime, in which participants must run 20 meters, exceed the marked line, and then run another 20 meters returning to the starting point, and between each movement (back and forth), there is a 10-second recovery time (Bangsbo et al., 2008; Castagna et al., 2006). The first stage starts with a speed of 10 $km \cdot h^{-1}$; between stages one and two, the increase in speed is 2 $km \cdot h^{-1}$; between stages two and three, the increase is 1 $km \cdot h^{-1}$. From the third stage onwards, the increase in speed between stages is 0.5 $km \cdot h^{-1}$, and participants remain in the test until maximum voluntary exhaustion. The variables to determine test performance in the Yo-Yo IR1 were the same used in the AIR-BT and BST.

Physiological and psychophysiological variables

HR was monitored throughout the tests (Polar® RS800, Kempele - Finland) with a chest strap transmitter. The HR was registered in the last 10 s of each stage. The HR_{max} was defined as the highest HR value observed in all tests. Earlobe capillary blood samples (25µl) were collected into a capillary tube in all tests to verify [La] before the start of the test (LA_{pre}), immediately at the end (LA_{post}), at the 3rd ($LA_{3\text{-}min}$) and 5th ($LA_{5\text{-}min}$) minutes after the end of the test to determine peak blood lactate concentration ($[La_{peak}]$). From these samples, blood lactate concentration was subsequently determined by the electro-enzymatic method using an automated analyzer YSI 2300 Stat® equipment (Yellow Springs Ind, Ohio – USA). LA_{peak} was defined for each participant as the highest post-exercise blood lactate concentration value (Machado et al., 2013). The Borg scale 6-20 (Borg et al., 1987) was used in all tests to measure the rating of perceived exertion (RPE) during the last 15 s of each stage and at exhaustion. The highest RPE value was adopted as the maximal RPE (RPE_{max}).

The maximal effort was deemed to be achieved if the incremental tests met two of the following criteria:

- $LA_{peak} \geq 8$ $mmol \cdot L^{-1}$ (Astrand, 1952);
- $HR_{max} \geq 95$ % of the HR predicted by age using the equation for trained people by Tanaka et al. (2001) (206 – 0.7 × age).
- $RPE_{max} \geq 19$ on the Borg scale 6-20 (Howley et al., 1995).

Data analysis

The Statistical Package for Social Science for Windows (SPSS® Inc. v.20, Chicago, IL, USA) was used to conduct the analysis. The normality assumption was verified using the Shapiro–Wilk test, and the results are presented as the mean ± SD. Sphericity was tested using Mauchly's test. Greenhouse–Geisser corrections were made when the assumptions of sphericity were violated. One-way ANOVA for repeated measures followed by Bonferroni *post hoc* test was used to evaluate the differences between physiological variables that resulted from the treadmill test, AIR-BT, BST, and Yo-Yo IR1. Separate linear regression models were fit to establish Pearson's product-moment correlations (r), coefficients of determination (R^2), and the standard error of the estimate (SEE) to examine the relationship between vLT and the different field tests. The correlation coefficients (r) were interpreted using the following qualitative descriptors: Trivial (<0.1), small (<0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), nearly perfect (>0.9), and perfect (1.0) (Hopkins et al., 2009). The Bland and Altman analysis determine the agreement between vLT with AIR-BT, BST, and Yo-Yo IR1, demonstrating the bias and the limits of agreement (LoA) (Bland and Altman, 1986). The significance level was set at $P < 0.05$ for all statistical analyses.

Results

The treadmill test lasted 27.1 ± 4.4 min, with athletes reaching the vLT at an intensity of 12.0 ± 1.0 km·h^{-1}, corresponding to 80.3 ± 4.8% of V_{max}. Performance in the AIR-BT was 15.4 ± 5.7 min, and a distance covered of 1172.5 ± 523.9 m; The BST test time was 15.9 ± 3.1 min, and a distance covered of 636.6 ± 184.6 m; and the Yo-Yo IR1 test time was 10.4 ± 2.3 min and distance covered of 1246.9 ± 316.9 m. Table 1 presents physiological and psychophysiological responses across the different protocols. LA_{peak} was lower in the BST compared to the other tests. Similarly, HR_{max} values were lower in the BST, particularly in comparison with the treadmill test – vLT and the AIR-BT. In contrast, the highest HR_{mean} values were observed in the AIR-BT, exceeding those found in the other protocols. Regarding perceptual responses, RPE_{max} values were also lower in the BST compared to the remaining tests.

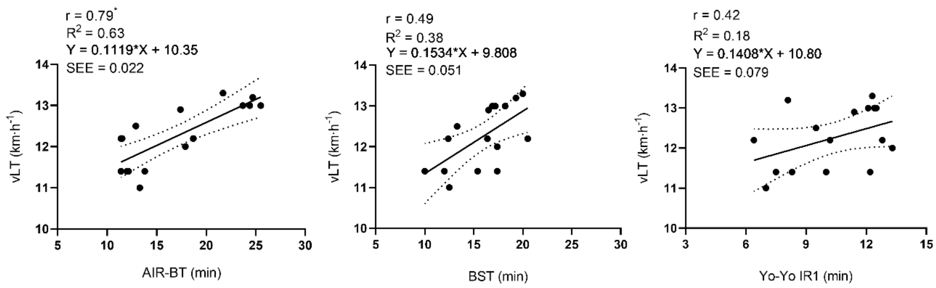
Table 1. Physiological and psychophysiological variables determined during the specific field tests and treadmill tests performed by badminton athletes (mean ± SD).

	Treadmill test - vLT	AIR-BT	BST	Yo-Yo IR1
LA_{peak} (mmol·L^{-1})	11.5 ± 2.9	12.0 ± 2.7	9.6 ± 2.0 $^{*\#}$	12.4 ± 2.8 †
HR_{max} (b·min^{-1})	197 ± 8.1	197 ± 8.7	192 ± 9.0 $^{*\#}$	193 ± 7.0
HR_{mean} (b·min^{-1})	162 ± 11.4	175 ± 8.0 *	168 ± 12.5 $^{\#}$	172 ± 8.3 *
RPE_{max}	19.8 ± 0.4	19.2 ± 0.9	17.5 ± 1.6 $^{*\#}$	19.4 ± 0.6 †

Note: N = 16; SD = standard deviation; vLT = Velocity at lactate threshold; AIR-BT = Abian intermittent recovery badminton test; BST = Badminton specific incremental test; Yo-Yo IR1 = Yo-Yo intermittent recovery test level 1; LA_{peak} = Peak blood lactate concentration; HR_{max} = Maximum heart rate; HR_{mean} = Mean heart rate; RPE_{max} = Maximum rating of perceived exertion.
* $P < 0.05$ compared to Treadmill test – vLT;
$^{\#}$ $P < 0.05$ compared to AIR-BT;
† $P < 0.05$ compared to BST.

Figure 1 shows the relation between each independent performance variable and the vLT. The AIR-BT (time) (r = 0.79, 95% CI: 0.50 to 0.92) showed a very large significant correlation with vLT. The BST (r = 0.49, 95% CI: 0.18 to 0.85) and Yo-Yo IR1 (r = 0.42, 95% CI: 0.13 to 0.76) values showed a moderate correlation with the vLT. Linear regression analysis indicated that the AIR-BT and BST significantly predicted 63% and 38% of the variance in the vLT.

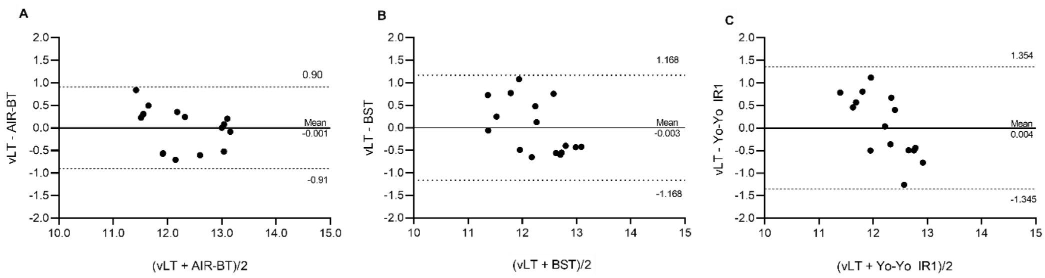
Figure 1. Correlation and linear regression between AIR-BT (A), BST (B), and Yo-Yo IR1 tests (C), with the vLT.



Note: vLT = Velocity at lactate threshold; AIR-BT = Abian intermittent recovery badminton test; BST = Badminton specific incremental test; Yo-Yo IR1 = Yo-Yo intermittent recovery test level 1; SEE = standard error of the estimate.

The Bland–Altman plots demonstrated the agreement between vLT and AIR-BT, BST, and Yo-Yo IR1 in Figure 2. The AIR-BT showed a mean bias of -0.001 km·h^{-1}, with limits of agreement ranging from -0.91 to 0.90 km·h^{-1}. Similarly, the BST and Yo-Yo IR1 presented mean biases of -0.03 and -0.04 km·h^{-1}, with limits of agreement from -0.003 to 1.168 km·h^{-1} and -1.345 to 1.354 km·h^{-1}, respectively.

Figure 2. Bland–Altman plots for the agreement between vLT and AIR-BT (A), BST (B), and Yo-Yo IR1 (C).



Note: vLT = Velocity at lactate threshold; AIR-BT = Abian intermittent recovery badminton test; BST = Badminton specific incremental test; Yo-Yo IR1 = Yo-Yo intermittent recovery test level 1.

Discussion

The present study aimed to examine the relationship and agreement between aerobic fitness assessed through specific field tests and the velocity associated with lactate threshold (vLT) in male badminton athletes. The second aim was to compare the physiological and psychophysiological variables between specific field tests and the vLT. The main finding was that AIR-BT showed higher correlation and agreement with vLT compared to BST and Yo-Yo IR1. In addition, physiological responses differed between the field-based protocols, indicating that each test imposes distinct physiological demands. These findings partially confirm our initial hypothesis and highlight the relevance of specific tests, such as AIR-BT, for estimating aerobic fitness in badminton athletes.

Taken together, the physiological responses observed across protocols indicate that, although all tests elicited maximal effort, the magnitude and profile of these responses were protocol-dependent. The lower LA_{peak}, HR_{max}, HR_{mean}, and RPE_{max} observed in the BST suggest a reduced physiological strain compared to the AIR-BT, Yo-Yo IR1, and treadmill test. This may be attributed to its continuous structure, shorter stage duration, and lower initial intensity and progression rate, which can delay the accumulation of metabolic stress. In contrast, the intermittent nature and higher intensity progression of the AIR-BT and Yo-Yo IR1 appear to promote greater physiological perturbation, more closely resembling the demands of high-intensity efforts (Abián-Vicén et al., 2021; Madsen et al., 2016; Fuchs et al., 2014; Wonisch et al., 2003).

Studies that examined the LA_{peak} response in the BST protocol found $LA_{peak} < 8$ mmol·L^{-1} (Lin et al., 2007; Wonisch et al., 2003). Wonisch et al. (2003), when validating the BST in 17 international male badminton athletes (26 ± 8 years old), reported an LA_{peak} value of 7.6 ± 2.1 mmol·L^{-1}. Lin et al. (2007) reported LA_{peak} values that varied between 6.5 ± 1.8 mmol·L^{-1} and 6.7 ± 1.4 mmol·L^{-1} of male badminton athletes in the BST protocol. Huang et al. (2026) examine the effects of a modified badminton field test on exercise-induced peripheral fatigue in 15 healthy male collegiate badminton players. The authors used the modified badminton footwork test (BFT) (Chin et al., 1995) and reported a LA_{peak} of 16.07 ± 2.52 mmol·L^{-1}. However, no other study has reported LA_{peak} values in the AIR-BT and Yo-Yo protocols performed by badminton athletes.

For the HR responses, Madsen et al. (2016) reported no significant difference in HR_{max} responses of 17 elite badminton athletes (27 ± 3.7 years) in Yo-Yo IR1 and B-ENDURANCE protocols, indicating that these two protocols overload maximum aerobic fitness in a similar way. However, specificity is lacking in the Yo-Yo IR1 because running does not resemble the movements and activation of the specific muscle groups utilized during badminton actions.

For the BST protocol, Lin et al. (2007) reported RPE_{max} = 20 ± 1 and HR_{max} = 194 ± 5 bpm^{-1} in 10 male badminton athletes. However, we highlight that in the study by Lin et al. (2007), a recovery period of 10 s was given between stages, allowing athletes to better recover between stages and remain in the protocol for a longer period, which is the potential reason why athletes achieved longer distances and higher HR_{max} and RPE_{max} values in the protocol in relation to the results of the current study.

It is important to mention that among the field-specific protocols, the BST has shorter stages (*i.e.,* 1 min), with no pause between stages, unlike the AIR-BT and Yo-Yo protocols which have longer stages and a 10 s pause for passive recovery between actions (Abián-Vicén et al., 2021; Bangsbo et al., 2008; Wonisch et al., 2003). Furthermore, it was observed that the initial speed in the BST (*i.e.,* 0.60 $m \cdot s^{-1}$ which corresponds to 2.16 $km \cdot h^{-1}$) allows the athlete to move around in the first stages, with movements that do not characterize the modality, due to their low speed and the low rate of increase in intensity (*i.e.,* 0.10 $m \cdot s^{-1}$ which corresponds to 0.36 $km \cdot h^{-1}$), unlike other protocols which have a higher initial intensity and increments that vary between 0.5 and 1.0 $km \cdot h^{-1}$ (Abián-Vicén et al., 2021; Bangsbo et al., 2008; Madsen et al., 2016). In other words, during the BST protocol, athletes make continuous efforts, especially in the final stages, different from other protocols, in which intermittent actions are performed at high intensity, similarly to a badminton match (Huang et al., 2026; Nagano et al., 2020; Tomaszewski et al., 2018).

This is the first study to demonstrate the relationship between badminton-specific field tests and vLT in badminton athletes. These results are in accordance with previous studies that demonstrated a higher correlation between badminton-specific field tests and physiological variables, such as $\dot{V}O_{2max}$ and physiological responses in the MLSS (Abián-Vicén et al., 2021; Wonisch et al., 2003). However, it must be emphasized that, unlike the method used in this study, Abián-Vicén et al. (2021) validated the AIR-BT based on its ability to estimate $\dot{V}O_{2max}$ obtained during a treadmill incremental test. In their study, significant correlations were observed between AIR-BT performance and $\dot{V}O_{2max}$ ($r = 0.87$), as well as with Yo-Yo IR1 performance ($r = 0.86$), and a regression model was proposed to predict $\dot{V}O_{2max}$ from AIR-BT time, with no significant differences between measured and estimated values.

Similarly, Wonisch et al. (2003) developed and validated a BST and reported strong correlations between the velocity and HR obtained during the incremental test and those derived from MLSS conditions for the HR responses and velocity (*i.e.,* $r = 0.78$ and $r = 0.93$, respectively), supporting the validity of the protocol to estimate submaximal aerobic performance. In addition, the MLSS test performed at an intensity slightly below the individual physical working capacity resulted in stable blood lactate concentrations (≈ 3.1 $mmol \cdot L^{-1}$), indicating that the protocol was able to reflect conditions close to MLSS.

In contrast, Fuchs et al. (2014) investigated the physiological determinants of performance in the BFT originally proposed by Chin et al. (1995), with particular focus on the individual anaerobic threshold (IAT). The authors reported only moderate correlations between the IAT obtained in this badminton-specific test and that derived from a multistage running test ($r = 0.63$), with approximately 40% of the variance explained. These findings suggest that a substantial portion of the physiological factors influencing test performance remained unaccounted for, indicating limited sensitivity of the protocol to reflect underlying aerobic fitness. Although referring to a different badminton-specific protocol, these results reinforce that not all field tests are equally valid for estimating submaximal physiological markers. In line with this, the present study also demonstrated weaker correlations between BST and Yo-Yo IR1 with vLT compared to AIR-BT.

Despite the relevant findings, some limitations of the present study should be acknowledged. First, the inclusion of only national-level male athletes may limit the generalizability of the results to elite international male and female athletes. Additionally, environmental conditions (*e.g.,* wind speed and slight temperature variations) were not strictly controlled during the field tests, which may have influenced performance outcomes. Although participants were instructed to maintain consistent dietary habits, no dietary control or recall was implemented, which may have affected physiological responses. Future studies should include female athletes and larger samples to better understand potential sex-related differences in physiological responses and aerobic performance in badminton.

Conclusions

In conclusion, the AIR-BT is a valid and practical tool for estimating vLT in badminton athletes, outperforming the BST and Yo-Yo IR1 in terms of correlation and agreement. The differences in physiological responses between protocols highlight the importance of test specificity when assessing aerobic fitness. By moving beyond traditional maximal indicators such as $\dot{V}O_{2max}$, this study provides novel evidence supporting the use of the AIR-BT for estimating aerobic fitness. These findings contribute to a more comprehensive understanding of aerobic assessment in badminton and reinforce the importance of test specificity for accurately capturing physiologically meaningful parameters

Acknowledgements

The authors would like to acknowledge the participants of the present study, the Badminton Federation of Paraná (BFP), and the CAPES Foundation, Ministry of Education of Brazil, for the regular scholarship.

Financing

This study was financed in part by the "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001".

References

Abián-Vicén, J., Bravo-Sánchez, A., & Abián, P. (2021). AIR-BT, a new badminton-specific incremental easy-to-use test. *PloS one*, *16*(9), e0257124. https://doi.org/10.1371/journal.pone.0257124

Alves, J. C., Peserico, C. S., Nogueira, G. A., Machado, F. A. (2017). Influence of continuous and discontinuous graded exercise tests with different initial speeds on peak treadmill speed. *Science & Sports* 32(1): e15–e22. https://doi.org/10.1016/j.scispo.2016.08.003

Åstrand PO. *Experimental Studies of Physical Working Capacity in Relation to Sex and Age.* Copenhagen: Munksgaard, 1952.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The Yo-Yo intermittent recovery test : a useful tool for evaluation of physical performance in intermittent sports. *Sports medicine (Auckland, N.Z.)*, *38*(1), 37–51. https://doi.org/10.2165/00007256-200838010-00004

Billat L. V. (1996). Use of blood lactate measurements for prediction of exercise performance and for control of training. Recommendations for long-distance running. *Sports medicine (Auckland, N.Z.)*, *22*(3), 157–175. https://doi.org/10.2165/00007256-199622030-00003.

Bland, J. M., and Altman, D. G. (1986). Statistical methods for assessing agrément between two methods of clinical measurement. Lancet 1, 307–310. doi: 10.1016/S0140-6736(86)90837-8.

Borg, G., Hassmén, P., & Lagerström, M. (1987). Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *European journal of applied physiology and occupational physiology*, *56*(6), 679–685. https://doi.org/10.1007/BF00424810

Cádiz Gallardo, M. P., Pradas de la Fuente, F., Moreno-Azze, A., & Carrasco Páez, L. (2023). Physiological demands of racket sports: a systematic review. *Frontiers in psychology*, *14*, 1149295. https://doi.org/10.3389/fpsyg.2023.1149295

Casado, A., Foster, C., Bakken, M., & Tjelta, L. I. (2023). Does Lactate-Guided Threshold Interval Training within a High-Volume Low-Intensity Approach Represent the "Next Step" in the Evolution of Distance Running Training?. *International journal of environmental research and public health*, *20*(5), 3782. https://doi.org/10.3390/ijerph20053782.

Castagna, C., Impellizzeri, F. M., Chamari, K., Carlomagno, D., & Rampinini, E. (2006). Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: a correlation study. *Journal of strength and conditioning research*, *20*(2), 320–325. https://doi.org/10.1519/R-18065.1

Chin, M. K., Wong, A. S., So, R. C., Siu, O. T., Steininger, K., & Lo, D. T. (1995). Sport specific fitness testing of elite badminton players. *British journal of sports medicine*, *29*(3), 153–157. https://doi.org/10.1136/bjsm.29.3.153

Faude, O., Kindermann, W., & Meyer, T. (2009). Lactate threshold concepts: how valid are they?. *Sports medicine (Auckland, N.Z.)*, *39*(6), 469–490. https://doi.org/10.2165/00007256-200939060-00003

Fischer, J., Hävecker, F., Ji, S., Wahl, P., & Keller, S. (2025). Modeling lactate threshold in cycling-influence of sex, maximal oxygen uptake, and cost of cycling in young athletes. *European journal of applied physiology*, *125*(8), 2145–2158. https://doi.org/10.1007/s00421-025-05744-y

Forsyth, J., Burt, D., Ridley, F., & Mann, C. (2017). Using lactate threshold to predict 5-km treadmill running performance in veteran athletes. *Biology of sport*, *34*(3), 233–237. https://doi.org/10.5114/biolsport.2017.65999

Fuchs, M., Faude, O., Wegmann, M., & Meyer, T. (2014). Critical evaluation of a badminton-specific endurance test. *International journal of sports physiology and performance*, *9*(2), 249–255. https://doi.org/10.1123/ijspp.2012-0387

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and science in sports and exercise*, *41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Howley, E. T., Bassett, D. R., Jr, & Welch, H. G. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and science in sports and exercise*, *27*(9), 1292–1301. https://doi.org/0195-9131/95/2709-129S3.00/0

Huang, H., Song, J., Huang, H., Zeng, Y., Li, X., & Liu, S. (2026). Effects of the modified field test on exercise-induced peripheral fatigue in non-elite badminton players. *Frontiers in physiology*, *17*, 1734224. https://doi.org/10.3389/fphys.2026.1734224

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P. K., & Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine and science in sports and exercise*, *35*(4), https://doi.org/10.1249/01.MSS.0000058441.94520.32

Lin, H., Tong, T. K., Huang, C., Nie, J., Lu, K., & Quach, B. (2007). Specific inspiratory muscle warm-up enhances badminton footwork performance. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme*, *32*(6), 1082–1088. https://doi.org/10.1139/H07-077

Machado, F. A., Kravchychyn, A. C., Peserico, C. S., da Silva, D. F., & Mezzaroba, P. V. (2013). Effect of stage duration on maximal heart rate and post-exercise blood lactate concentration during incremental treadmill tests. *Journal of science and medicine in sport*, *16*(3), 276–280. https://doi.org/10.1016/j.jsams.2012.08.003

Madsen, C. M., Højlyng, M., & Nybo, L. (2016). Testing of Badminton-Specific Endurance. *Journal of strength and conditioning research*, *30*(9), 2582–2590. https://doi.org/10.1519/JSC.0000000000001350

McKay, A.K.A., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., Sheppard, J., Burke, L.M. (2021). Defining Training and Performance Caliber: A Participant Classification Framework. *International Journal of Sports Physiology and Performance* , 17, 317–331. https://doi.org/10.1123/ijspp.2021-0451.

Nagano, Y., Sasaki, S., Higashihara, A., & Ichikawa, H. (2020). Movements with greater trunk accelerations and their properties during badminton games. *Sports biomechanics*, *19*(3), 342–352. https://doi.org/10.1080/14763141.2018.1478989

Peserico, C. S., Mezzaroba, P. V., da Silva, D. F., Kravchychyn, A. C. P., Alves, J. C. C., & Machado, F. A. (2018). Blood lactate concentrations following maximal incremental test in male runners with different ages. *Revista Brasileira de Educação Física e Esporte,* *32*(1), 5–15. https://doi.org/10.11606/1807-5509201800010005

Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports medicine (Auckland, N.Z.)*, *45*(4), 473–495. https://doi.org/10.1007/s40279-014-0287-2

Støa, E. M., Helgerud, J., Rønnestad, B. R., Hansen, J., Ellefsen, S., & Støren, Ø. (2020). Factors Influencing Running Velocity at Lactate Threshold in Male and Female Runners at Different Levels of Performance. *Frontiers in physiology*, *11*, 585267. https://doi.org/10.3389/fphys.2020.585267

Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology*, *37*(1), 153–156. https://doi.org/10.1016/s0735-1097(00)01054-8

Tomaszewski, P., Kęska, A., Tkaczyk, J., Nowicki, D., & Sienkiewicz-Dianzenza, E. (2018). Somatic characteristics and motor fitness of elite and sub-elite Polish male badminton players. *The Journal of sports medicine and physical fitness*, *58*(10), 1456–1464. https://doi.org/10.23736/S0022-4707.17.07279-6

Wonisch, M., Hofmann, P., Schwaberger, G., von Duvillard, S. P., & Klein, W. (2003). Validation of a field test for the non-invasive determination of badminton specific aerobic performance. *British journal of sports medicine*, *37*(2), 115–118. https://doi.org/10.1136/bjsm.37.2.115

Authors and translators' details:

Gabriel Henrique Ornaghi de Araujo	ornaghi.gabriel7@gmail.com	Author
Cecília Segabinazi Peserico	ceciliapeserico@gmail.com	Author
Layla Maria Campos Aburachid	laylabur@hotmail.com	Author
Fabiana Andrade Machado	famachado@uem.br	Author